THE EFFECT OF RESTRICTED EXERCISE ON SOW BEHAVIOUR AND REPRODUCTIVE PERFORMANCE

MARGARET A. PARRY, B.Sc.

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ABSTRACT

20 Large White x Landrace sows were kept throughout 4 parities on 1 of 2 exercise treatments, free (F) or restricted (R), imposed at 2 stages of the production cycle (namely gestation and farrowing/lactation), thus giving 4 treatments: FF, FR, RF and RR. During gestation, the sows were housed in cubicles - group R being tethered while group F were allowed unrestricted movement within the cubicle and dunging area. From day 110 of gestation to weaning, all sows were kept in the same farrowing house, group R in conventional crates, group F in strawed pens. Management of the sows was otherwise identical. All farrowings were monitored with regard to the duration of parturition and stillbirth rate, while various behavioural and physiological measurements were recorded as indicators of piglet viability. Observations were also made of sow behaviour at various stages of the production cycle. There were significant ($P<0.001$) behavioural differences in gestation with groups R and F spending 45% v. 25% of the time lying and 27% v. 42% in manipulating straw. There were also significant ($P<0.001$) differences in amount and type of locomotor activity with the restricted sows making more minor movements while the free sows made more pace movements. At farrowing, all sows showed increased restlessness but group R made more leg movements and exhibited significantly ($P<0.01$) more straining and quivering (both pre- and intrapartum) than group F, although the latter stood and nested more frequently during the farrowing process ($P<0.001$). There were no significant differences between treatments during lactation. In terms of reproductive performance, the differences between treatments were non significant, but sows in pens (group F) farrowed more quickly (a mean birth interval of 21 v. 39 mimutes), produced more live pigs (11.3 v. 10.5) and fewer stillborn pigs (0.5 v. 0.8) per litter, than sows in crates (group R). Group F sows also

produced piglets which had been subjected to less hypoxia as evidenced by their lower ($P < 0.05$) serum lactic acid levels at birth (140 v. 158 m.I.U./ml) although there were no significant differences between piglets of groups F and R in times taken to breathe following birth (53 v. 45 seconds), to suckle (36 v. 32 minutes) or in plasma immunoglobulin levels at 36 hours post partum (41.5 v. 41.7 mg/ml). Neither were there any significant treatment effects on piglet growth rate and pre-weaning mortality.

INTRODUCTION

The public debate over animal welfare issues such as the close confinement of pregnant and lactating sows is one of the topics confronting the agricultural industry today. Systems which involve the tethering of dry sows and the use of farrowing crates tend to lead to emotional arguments, but in order to arrive at a reasonable assessment of such systems, emotion must be replaced by informed opinion. There have been several attempts to compare sow behaviour and production under both intensive and less restricted conditions but virtually all of these have involved comparatively short term studies whereas, from a commercial viewpoint, a producer needs to know the long term effects of a particular system on the lifetime production of his sows. However strong the moral issues, a commercial producer will be more likely to look towards alternatives only if his present system is shown to be economically disadvantageous.

The purpose of a breeding sow is to produce the maximum number of healthy weaners and so all aspects of the reproductive process are of fundamental importance to the producer. As a species, the pig suffers from extremely high pre- and post-natal mortality and it must always be the aim of every management system to minimise this. Environmental factors can affect mortality at every stage of the reproductive process and in particular, unsuitable housing may create conditions of psychological and/or physiological stress which, by causing alterations of the maternal hormone balance, may have severe effects on the developing embryos or cause disruption of the normal farrowing process. In common with all mammalian birth, farrowing relies on co-ordinated contractions of both smooth and skeletal muscles and any impairment of the muscle action may lead to an extended farrowing and an increased

risk of stillborn piglets due to premature rupture of the umbilical cord. Good muscle tone is also important for an efficient farrowing process and any deterioration in this as a result of closely confining sows throughout gestation may also cause problems with prolonged farrowings. Even if a piglet is not born dead, it may be born suffering from partial asphyxiation which could lead to increased mortality in the immediate post-natal period due to a decreased intake of colostrum and a greater risk of being chilled or overlain. The housing system also affects the behavioural pattern of the sow both before and after farrowing and thus can also influence the level of piglet mortality.

It is the aim of the studies reported in this thesis to provide further information about the long term reproductive performance and behaviour of sows kept under varying degrees of confinement so that a reasoned judgement may be made as to which type of system is optimal for both the sow and the producer.

Section 1

LITERATURE REVIEW

Chapter 1

THE FARROWING PROCESS

1.1 Introduction

The importance of farrowing is emphasised by Noirrit (1979) who claimed that it is the culmination of nearly 4 months investment in labour, food and buildings and that the investment needs to be recouped at this stage. The term "farrowing" is a composite one covering many different aspects and events which will be considered in turn.

1.2 Length of gestation

Farrowing occurs after a fairly well defined length of gestation (table 1.1). Various factors are thought to influence gestation length including breed (table 1.2), although Lynch (1965) found no significant differences in gestation length between Large White, Landrace and Crossbred Sows.

Table 1.1 Estimates of gestation length in pigs

Author	Year	Gestation length (days)
Bille et al	1974 a)	71% betw. 112-116
Bonte et al	1982	Mean 115
Cox	1967	Mean 113.4
DeRoth & Downie	1976	Mean 114(111-117)
First	1978	112-116
Heidler & Huhn	1982	115.4
Jones	1966 a)	Mean 112(110-116)
Lynch	1965	Mean 114.5
Sinclair & Syrotuck	1928	Mean 114.6
Vanstalle et al	1981	107-123

Table 1.2 Effect of breed on gestation length

Author	Year	Breed	Gestation length (days)	
Cox	1964	Hampshire	113.24	P< 0.01
		Duroc	113.74	
Garnett & Rahnefeld	1979	Lacombe	114. 4	P< 0.01
		Yorkshire	115.8	

The influence of parity on gestation length is not clear as, while some reports indicate no effect (e.g. Lynch, 1965), others report a positive relationship between increasing parity and gestation length (table 1.3) although the differences are rarely significant.

Table 1.3 Effect of parity on gestation length

Author	Year	Gestation length (days)					
	Parity 1	2	3	4	5	6	
Bus'ko	1975	115-118	farrow nearer to day 119				
Stepulenkova & Sukhorukov	1977	114.9	114.8	115.1	115.0	115.0	114.9

It might be expected that litter size would influence gestation length but neither Cox (1964, 1967) nor Baik, Park, Ohh and Han (1977) found any significant effect. As far as exercise is concerned, Krutyporokh (1965) claimed a smaller range in gestation lengths of Ukrainian White Steppe Sows which had undergone strenuous exercise (112-117 days) compared to control sows (110-119 days) which had not been forced to exercise.

1.3 Hormonal control of parturition

The subject has been comprehensively reviewed by First (1978) and is represented schematically in fig. 1.1. During pregnancy, progesterone is produced by the corpora lutea and is important

in suppressing myometrial activity. The presence of foetuses (or foetal tissue) is necessary to maintain the corpora lutea (and thus to maintain pregnancy) as shown by experiments in which all the foetuses were removed from a pregnant sow at day 102, causing expulsion of the placenta in less than 48 hours.

For a normal parturition to occur, the mechanisms for the maintenance of pregnancy must cease to function and luteolysis must occur so that the progesterone block is removed. According to First, Lohse and Nara (1982), the message initiating parturition starts with the foetal brain and is followed by release of adrenocorticotrophic hormone (ACTH) and a rise in plasma cortisol levels. The foetal adrenal gland greatly increases its capacity for glucocorticoid production in late gestation and the increasing cortisol levels then stimulate an (as yet unknown) intermediate which causes the uterus to produce and release $PGF_{2\alpha}$. This latter terminates the production of progesterone from the corpora lutea so that the myometrium is now able to start contracting and the intensity of the contractions increases due to the stimulatory effect of prostaglandin and (later) oxytocin.

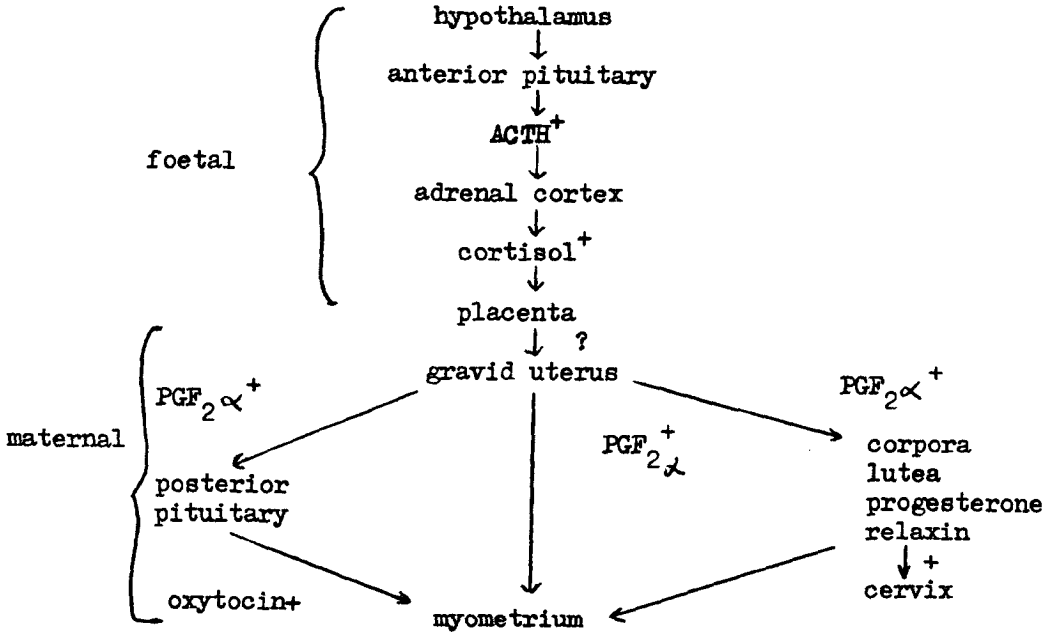
First (1978) stated that it is certain that ACTH in the foetus controls the production of cortisol by the adrenals, but that at present it is not known what regulates the secretion of ACTH during the last days of pregnancy; possibly the whole conceptus must reach a certain stage of maturity before the foetal corticoids can initiate parturition.

It has been proposed (Wagner, Thompson, Evans &Molokwu, 1974) that a stimulus to the foetal hypothalamus invokes the foetal pituitary-adrenal axis to increase glucocorticoid secretion. They suggested

that this stimulus may be already present, but it may only produce a reaction when the hypothalamus has fully matured or alternatively, it may result from changes in other body organs such as the liver or kidney. Increase in adrenal corticoid secretion by the foetus may provide additional precursors for an increased oestrogen synthesis by the placenta. The uterus would then start to produce prostaglandin which in turn would cause a decrease in progesterone and an increase in oxytocin and oestrogen production. This change to oestrogen dominance prepares the uterus for a stronger and more rhythmic response to the process of foetal expulsion (fig. 1.1).

Fig. 1.1 Possible sequence of events resulting in farrowing

(from First, 1978)



? unknown
+ stimulatory effect

Even a simplified scheme such as fig. 1.1 indicates that many different hormones are involved in initiating parturition although First (1978) claimed that the level of progesterone is the overriding factor controlling its onset as, if this declines, parturition will occur

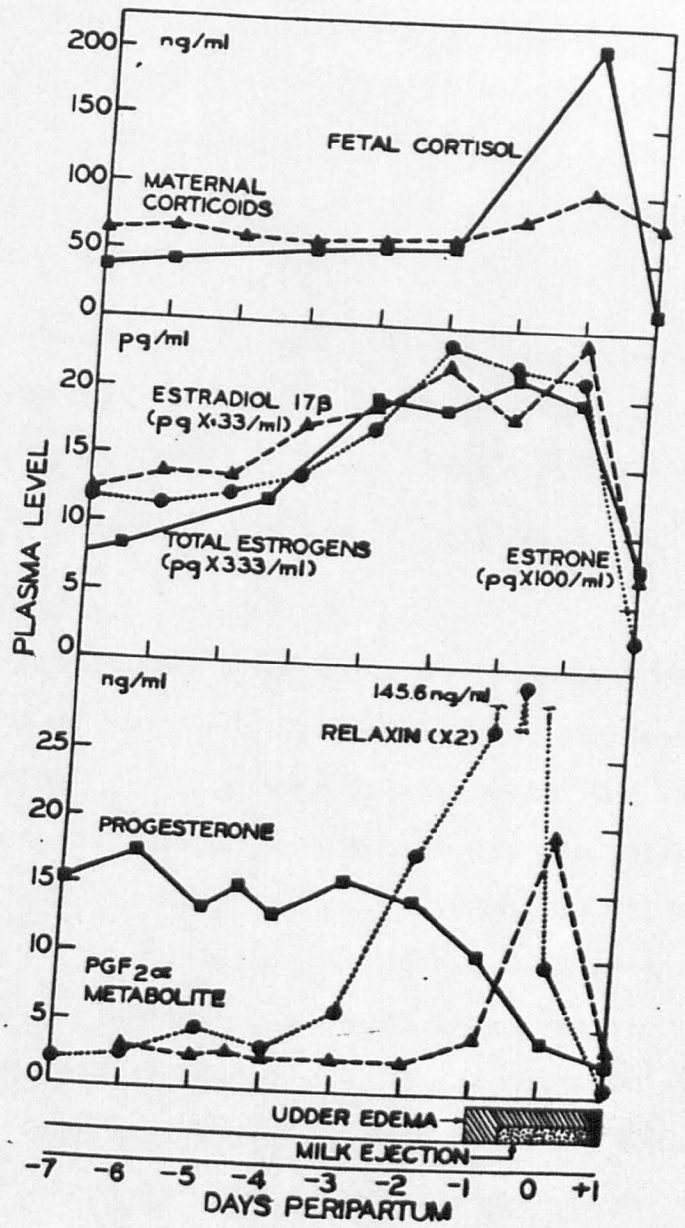
but if the level is maintained, birth will not take place despite the normal changes in other hormones.

Many workers have examined the hormone changes around parturition e.g. Belt, Anderson, Cavazos and Melampy (1971); Ash, Banks, Bailes, Broad and Heap (1973); Molokwu and Wagner (1973); Robertson and King (1974); Fevre, Terqui and Bosc (1975); Sherwood, Chang, BeVier and Dzuik (1975); Sherwood, Chang, BeVier, Diehl, Dzuik (1976); Coggins (1976); Silver, Barnes, Comline, Fowden, Clover and Mitchell (1979); Taverne, Willemse, Dieleman and Bevers (1979); Taverne, Naaktegeboren, Elsaesser, Forsling, van der Weyden, Ellendorff and Smidt (1979); Brenner, Gurtler, Muller and Grun (1981). Consideration of their results enabled First (1978) to compile composite graphs to illustrate endocrine changes preceding farrowing (fig. 1.2).

In summary, the steep rise in foetal corticoid levels is paralleled by a much smaller rise in maternal corticoids and the effect of this is to cause an increased production of oestrogen from the placenta so that oestrogen levels reach a maximum at farrowing. This increased concentration of oestrogen leads in turn to an increase in prostaglandin synthesis which brings about a rapid regression of the corpora lutea so that progesterone levels decline rapidly over the 48 hours prior to farrowing.

The dramatic increase in relaxin levels approximately 72 hours prior to farrowing is likely to be associated with cervical dilatation as Zarrow, Sikes and Neher (1954) showed that injections of relaxin produced cervical dilatation in non pregnant gilts in addition to considerable vulva oedema, such as is characteristic of parturient animals. These findings have been confirmed in sows where it has

Fig. 1.2 ENDOCRINE CHANGES PRECEDING PARTURITION IN SWINE



(from First, 1978)

been shown that relaxin brings about a depolymerisation of the ground substance in the cervical connective tissue leading to an increased water content, loss of tonus and a general softening which would allow the passage of large objects (Zarrow, Neher, Sikes, Brennan and Bullard, 1956; Steinetz, O'Byrne and Kroc, 1980). In addition to its role in cervical dilatation, Sherwood, Martin, Chang and Dzuik (1977) speculated that relaxin may also have a role in the initiation of parturition while Sherwood, Nara, Crnekovic and First (1979) concluded that the prepartum relaxin surge is somehow associated with prostaglandins.

In conclusion, with so many interacting hormonal factors involved in initiating farrowing, it is perhaps not surprising that sometimes the process goes awry and an increase in the stillbirth and/or neonatal mortality rate is the result.

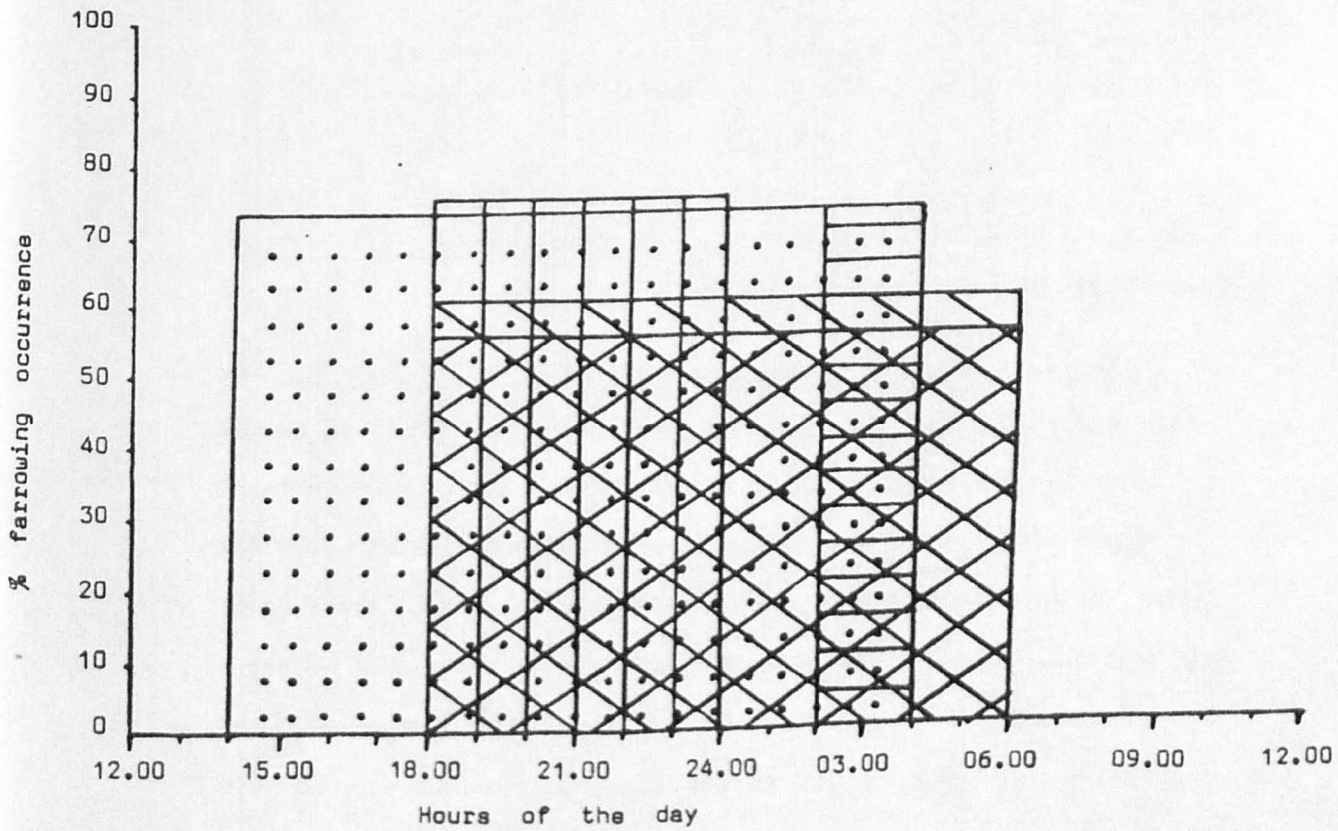
1.4 Time of day when farrowing occurs

There is general agreement in the literature that most farrowings occur at night or in the early hours of the morning (fig. 1.3 and table 1.4). Fraser (1968) postulated that adrenalin, which is produced by aroused animals, may be responsible for inhibiting birth during periods of great activity or excitement. During the quieter hours, adrenalin levels fall and they no longer block the action of oxytocin so the birth process can start. Rossdale and Short (1967) showed the existence of a definite circadian rhythm for the time of foaling in mares, in which 86% occurred between 19.00 and 0.700. They speculated that for animals which do not give birth in a nest, the process of parturition would be subjected to a particularly heavy selection pressure and so there might be some adaptive significance of giving birth at night when the possibilities for concealment would be at a maximum. However, this

Table 1.4 Nocturnal pattern of farrowings

Author	Year	Time of day when farrowing occurred	Code (in fig. 1.3)
Asdell	1946	73% between 14.00-04.00	·····
Deakin & Fraser	1935	73% between 02.00-04.00	———
DeRoth & Downie	1976	75% between 18.00-24.00	|||
Dinu et al	1980	72% at night	
Fahmy & Friend	1981	55% between 18.00-06.00	\\\\
Fraser	1974	More often at night	
Friend et al	1962	60% between 18.00-06.00	\\\\

Fig. 1.3 Nocturnal pattern of farrowings



is also the time of greatest predator activity, so the significance of such a rhythm is uncertain.

1.5 Signs of approaching parturition in the sow or gilt

i. Body temperature

The period before farrowing in a sow is characterised by a rise and subsequent fall in body temperature according to Littledike, Witzel and Riley (1979) who recorded a mean body temperature of 38.6°C which rose to a maximum of 40.3°C 12 hours prepartum before decreasing again. A similar pattern has also been reported by Curtis, Kelley and Ross (1976) in table 1.5

Table 1.5 Changes of body temperature in farrowing pigs kept at an environmental temperature of 21°C

Mean rectal temperature (°C) during the period:

	Day 109 of gestation to 4 hours before 1st delivery	4 hours prior to 1st delivery	During farrowing	After farrowing
Gilts	39.39	39.78	40.72	40.28
Sows	39.22	39.78	40.61	40.0

(from Curtis, Kelley and Ross, 1976)

ii. Enlargement of the udder and presence of mammary secretions

One or two days before farrowing individual glands become clearly demarcated and turgid, while the skin of the udder becomes warm and milk can be expressed from prominent teats during the final 12-24 hours (Jones, 1966a; Arthur, 1975; Hartsock and Graves, 1976). However, failure to achieve expression of milk does not preclude the possibility of imminent parturition (Fraser, 1971). The presence of mammary secretions before farrowing is very variable (Jones, 1966a;

Randall, 1968); they may be present in some teats and not others, or may be detected at one examination but not at the next. In some sows a straw coloured serous fluid could be detected before milk, but other sows showed no secretion until true colostrum appeared (Randall, 1968).

iii. Appearance of the external genitalia

The vulval lips start to swell about 4 days before farrowing although the degree of swelling can vary considerably (Jones, 1966a; Randall, 1968). The mucosa generally remains dry until the birth of the first pig (Jones, 1966a).

iv. Behaviour of the sow or gilt prior to farrowing

During pregnancy, sows become more docile and their amount of physical activity is reduced (Baldwin, 1969) but most authors have not observed any significant change in behaviour until the 24 hours prior to farrowing when there is a noticeable increase in restlessness, to the extent that most sows change their position every few minutes (Jones, 1966a). They also show an increased respiratory rate and frequently exhibit intermittent grunting and champing of the jaws. When they apparently become exhausted by all this activity, they lie down to rest and this alternating pattern is repeated until approximately 15–60 minutes before the birth of the first piglet, when they become quieter (Jones, 1966a). The extent of the restlessness varies markedly between different individuals; restless sows in crates frequently grind their teeth, bite the rails or attempt to lift them using their snouts (Randall, 1968; Signoret, Baldwin, Fraser and Hafez, 1975).

It is possible that the conditions in which sows are housed during this period affects their behaviour as Hansen and Curtis (1980) observed sows during the 48 hour prepartum period and concluded that confining them to a farrowing stall at this time significantly influenced their behaviour i.e. they became more restless.

In the immediate prepartum period, the sow starts to utter gentle deep throated grunts, interspersed with short, shrill whining sounds (Hafez, Sumption and Jakway, 1962). There is strong behavioural evidence of the build up of pain at this stage (Fraser, 1974) and sows frequently make abdominal straining movements with the hind upper limb drawn forwards as well as undergoing frequent bouts of shivering in between the straining (Randall, 1968).

One behavioural characteristic which denotes approaching parturition is nest building and Naaktgeboren (1979) stated that nest building is an inevitable part of parturient behaviour, which occurs even if the construction of a specific nest is not possible. Despite many generations reared in domestication, this behaviour has not changed, in fact Naaktgeboren claimed it belongs to the genetic characteristics of the species. It is widely seen in parturient sows kept under extensive outdoor systems (Parry, 1981; Stolba and Wood-Gush, 1981), as well as in wild breeds (Staub, 1977) and many of the motor elements of nest building can still be seen in crated sows on concrete floors (Signoret et al., 1975).

The onset of nest building behaviour is variable, ranging from 3 days to a few hours prepartum (Fraser, 1974). In the sow, Naaktgeboren (1979) claimed that the onset of nesting behaviour coincides with a decrease in progesterone levels and an increase in prolactin;

Taverne et al (1979) also thought that the rise in prolactin was responsible for the initiation of nest building as Nicoll (1974) had suggested is the case in laboratory mammals. There have also been suggestions (Zarrow, Sawin, Ross, Denenberg, Crary, Wilson and Farooq, 1961) that a change in the progesterone : oestrogen ratio is the hormonal trigger for nest building as just before parturition, oestrogen levels are higher than progesterone.

The behaviour of sows at this time depends on the bedding provided e.g. wood shavings are rearranged with the snout and forelegs whereas straw is often chewed before being deposited on the ground and sows generally make their bed several times before settling down (Randall, 1968). In $25m^2$ deep strawed pens, parturient sows moved around the pen gathering large mouthfuls of straw and depositing them in a corner. They then burrowed into the centre of this pile with powerful rooting and pawing movements which resulted in the formation of a large cup-shaped nest about 1.75m diameter and with a perimeter 0.5m higher than the original straw in the pen (Baxter and Petherick, 1980). Normally, the sow makes a nest in such a way that when she is lying down, the rim of the nest is a few centimetres away from her belly and the piglets lie in this space at a temperature of $38^{\circ}C$ (Pomeroy, 1953). Under natural conditions, the sow may attempt to clean and dry her selected birth site and will chew long grass, straw, dry leaves etc. to provide bedding, often carrying it a considerable distance. She also frequently resists human attempts to disturb or relocate her nest (Fraser, 1974; Parry, 1981).

1.6 Behaviour of the sow or gilt at farrowing

The great increase in restlessness as farrowing approaches has already been noted and English, Smith and MacLean (1977) considered that this continued into the second phase i.e. piglet expulsion.

They observed that sows often have the habit of standing up or squatting after each of the early piglets has been born as if to examine the new arrivals. They also speculated as to whether savaging of newborn piglets is really misdirected exploratory behaviour. Jones (1966b) also noted that sows stood up more frequently after the birth of the first one or two piglets than after subsequent ones.

There appears to be some differences in behaviour at farrowing between sows and gilts. Randall (1972a) noted that some gilts were mildly disturbed after the birth of the first few piglets, particularly if they approached the gilt's head, but this behaviour generally ceased when piglets found a teat and started to suckle. Henry (1969) described cases of parturient psychosis in gilts in which the gilt frequently rose to her feet between births and appeared nervous, reacting in a frightened fashion to even mild stimuli. If piglets approached her head, she often snapped at them, sometimes even fatally injuring her whole litter. In most cases, the gilt made no attempt to allow the piglets to suckle; Lewis and Oakley (1970) described a similar condition and stated that it was common in some herds. English (1969) noted that older sows moved less during farrowing than younger sows and that gilts appeared the most restless. He also observed that some movements of farrowing sows and gilts are stimulated by activities which take place outside the pen but inside the house and he considered that this could be important in modern crate farrowing houses.

The major sow activity seems to occur during stage 2 of parturition (i.e. delivery of piglets) rather than stage 3 (expulsion of placenta) (table 1.6).

Table 1.6 Activity of 31 sows during farrowing

	Stage 2	Stage 3
No. major movements/hour	2.0	0.34
No. minor movements/hour	3.1	0.7
Proportion of time spent lying on side	84%	95%

(from English et al., 1977)

Sows usually give birth in a position of lateral recumbency (Jones, 1966b; Baldwin, 1969; Randall, 1972a; Fraser, 1974; Arthur, 1975). The greatest parturient effort is expended over the first piglet whereas succeeding foetuses are expelled with ease and sometimes with considerable force (Arthur, 1975). The imminent delivery of a piglet is often heralded by vigorous tail swishing and sometimes by abdominal straining with the upper hind leg drawn forwards and there is frequently some expulsion of small volumes of fluid (sometimes bloodstained) between the delivery of individual piglets (Jones, 1966b; Randall, 1972a). The recumbent sow occasionally tries to stretch out and kick with her upper hind limb (Fraser, 1974).

1.7 Piglet birth order in relation to position within the uterus

There appears to be no specific order of delivery between right and left horns according to Dzuik and Harmon (1968) who operated on pregnant gilts and dyed the foetuses before parturition. Later research (Dzuik and Harmon, 1969) showed that the birth order within a horn corresponded to the order of foetuses within it (i.e. number one is closest to the cervix, number two is adjacent

and so on). These authors found no evidence that one foetus may pass another in the uterus although others disagree (e.g. Perry, 1954; Taverne, van der Weyden, Ellendorff, Elsaesser, Fontijne and Smidt, 1976). Further work has shown that piglets are delivered randomly from both horns; in 44.7% of cases, a piglet was born following its neighbour from the same horn, whereas in 55.3% of cases, it was expelled from the contra-lateral horn. In 18% of the sows examined, the contents of one entire horn were expelled before the other horn (Taverne, van der Weyden, Fontijne, Ellendorff, Naaktgeboren and Smidt, 1977).

1.8 Birth Presentation

Many authors have studied the presentation of piglets at birth and their results show a definite bias towards an anterior presentation (table 1.7) although the reason for this is not apparent.

Table 1.7 Observation of anterior presentation of piglets at birth

Author	Year	% of pigs born anteriorly
Arthur	1975	70
Dinu et al	1978	72
Dzuik & Harmon	1969	64
Dzuik et al	1972	65
Jones	1966b)	76
Randall	1968	58
Randall	1972a)	55
Reimers et al	1973	62

Some authors have also observed a trend for more pigs to be born anteriorly as farrowing progresses (Dzuik, Sprecher, Webel and Harmon, 1972; Reimers, Dzuik, Bahr, Sprecher, Webel and Harmon, 1973). However, Randall (1968) found the opposite trend and in his results, the differences between the first and final thirds of the birth order (of 66% v. 51%) were significant. There may also be an effect of dam age and litter size on birth presentation since Reimers et al (1973) found that more piglets were born anteriorly from sows with large litters than from gilts with small litters.

Finally, experiments involving laparotomy of sows at day 80-105 of pregnancy have shown that in 19% of cases, the presentation of the pig has changed over the last few weeks of pregnancy and that there are changes from anterior to posterior and vice versa, although the significance of this is not clear (Taverne, van der Weyden, Fontijne, Ellendorff, Naaktgeboren and Smidt, 1977).

1.9 Appearance of the piglet at birth

The snout or foot of a piglet may often be seen briefly protruding from the vulva only to be withdrawn as the uterus relaxes and to reappear later (Marrable, 1971). Once it has been delivered, the amnion adheres closely to the piglet's body at birth even though the rupture of the membrane and loss of amniotic fluid has occurred (Randall, 1972a) and many piglets have pellets or loose flakes of meconium between the amnion and their skin surface. Piglets which are born enveloped in membranes break free of these with their feet or as a result of vigorous body movements but if their muscular action is weak, they fail to escape and so die (Jones, 1966b).

Most piglets attempt to stand within one minute after birth and within

2 minutes have made attempts to free themselves from the sow and to suckle (Randall, 1968; 1972a). While only a very small (2.2%) proportion of piglets are incapable of moving around after birth (English, 1969).

1.10 State of the umbilical cord at birth

The umbilical cord in pigs is quite long (approximately 25 cm) according to Roberts (1971). It is also capable of considerable stretching; Perry (1954) noted that all the piglets may be delivered without the cord rupturing and Jones (1966b) and Randall (1972a) observed several cases in which piglets were able to suckle the posterior and middle teats of the sow before the cord broke.

Sometimes the cord shows evidence of pathologic symptoms; Jones (1966b) observed 3 cases of haematoma of the cord, while English (1969) saw some cases of severe knotting and twisting which restricted blood flow. About 30-40% of piglets are born with broken cords (table 1.8).

Table 1.8 State of umbilical cord at birth

Author	Year	% piglets born with broken cords
Jones	1966b)	28
Randall	1968	23.5
Randall	1972a)	39
Walters	1965	41

It has been suggested that later born piglets have a significantly greater frequency of cord breakage and when the litter was divided into thirds in respect of the birth order, the percentage of pigs born with broken cords was 13, 23 and 35 respectively (Randall, 1968).

The same author also noted that piglets born with a posterior presentation had a significantly higher rate of cord breakage than those born anteriorly (29% v. 19% respectively).

There is a general agreement that a large proportion of the cords which appear broken at birth have in fact only recently been broken, as the piglet was propelled along the pelvic canal (Perry, 1954; Roberts, 1971). Naaktgeboren (1979) claimed that the cord ruptures at a non-specific site while Randall (1979) stated that the strength of the cord appeared to vary between litters and he suggested that investigations into this might be of more practical benefit than attempts to resuscitate newborn pigs. In an earlier study, Randall (1968) had observed that many of the liveborn pigs with ruptured cords were weak and that probably if they had been subjected to a second stress such as a delay in delivery, they would have died. Certainly, if the cord remains intact after birth, there is a possibility that extra blood may drain into it from the placenta which would be advantageous (Baird, 1962).

Estimates of the time taken for a newborn piglet to break an intact cord range from one minute to 30 minutes (Jones, 1966b; Randall, 1968) and this was greatly influenced by the persistence of the individual. Hafez, Sumption and Jakway (1962) also reported that the cord is usually detached within 15 minutes of birth as the piglet tried to move away. Within 5 hours of birth, the cord has shrivelled and by 24 hours post partum it has shrunk considerably (Jones, 1966b).

1.11 Changes in placental attachment during farrowing

From day 26 of pregnancy onwards, the surface of each chorionic sac adheres firmly to the endometrium; the attachment being by the allantochorionic folds which are swollen with blood and locked into position in the endometrial crypts (Marrable, 1971). Accumulating foetal fluids press outwards against the tensed uterine muscle, which helps to support the weight of the membrane.

At farrowing, however, the drop in blood pressure which follows the severance of the umbilical cord results in the deflation of the allantochorionic folds and in the absence of supporting fluids, their attachment is weakened. As the membranes disengage, they collapse into the uterine cavity and are forced from the vulva by peristaltic waves.

Placental separation does not occur until the umbilical cord has ruptured and the resultant fall in blood pressure in the chorionic villi is of major importance in this process (Perry, 1954). Support for this proposal is provided by Jones (1966b) who showed that piglets delivered with intact cords had no apparent separation of the placenta.

Due to the contractions of the uterus, the attachments of the placenta to the endometrium become less intimate and the superficial cells undergo a fatty degeneration which leads to an increased resistance to blood flow on the maternal side and therefore a greater blood flow to the foetus (Arthur, 1975).

The ends of each placenta become fused with the adjacent ones, thus forming a continuous tube through which the piglets can pass (English et al, 1977) and the continuous slippery tube which may be formed will facilitate prompt delivery of the litter

(Marrable, 1971). Observations on a sow and gilt which were slaughtered after farrowing 1 and 4 piglets respectively showed that the chorionic sacs of the piglets were broken and they lay in one long slippery tube (Perry, 1954). Since the chorionic sacs rupture simultaneously at an early stage, this allows the foetuses with their long umbilical cords to move so that they pass one another, with the result that they are not necessarily born in order of their location in the uterine horn (Fraser, 1971).

1.12 Expulsion of the placenta

The time taken for the placenta to be expelled after farrowing is extremely variable with estimates ranging from 21 minutes to 12½ hours with a mean of 4 hours (Jones, 1966b) while according to Marrable (1971) the time ranged from 0 to 9 hours with a mean of 45 minutes and according to Arthur (1975), the mean time was approximately 4 hours. There is no apparent correlation between the size of the litter and the time taken to expel the membranes. Owing to the diffuse nature of the placental attachment, total retention of the placenta is very uncommon in sows (Zerobin and Sporri, 1972).

In polytocous species such as the pig, the second and third stages of labour (i.e. expulsion of foetuses and foetal membranes) are interrelated, thus it is possible to get expulsion of a single placenta after the birth of a particular piglet, although usually the joined allantochorions are expelled en masse after delivery of the entire litter (Arthur, 1975; Fraser, 1974).

1.13 Behaviour of the sow or gilt after farrowing

Once farrowing is over, the sow usually stands up for a few minutes and urinates copiously, she also frequently defaecates (Jones, 1966b). Many sows are placentophagic and this is probably an evolutionary trait which removes evidence of the presence of a vulnerable neonate.

Free-ranging sows usually keep their newborn litter close to the birth site for several days (Fraser, 1974) and only leave the nest for very short periods in order to eat, drink, defaecate etc. (Parry, 1981).

Following parturition, the sow often calls her litter to suckle by emitting repeated short grunts and she sometimes appears to position the piglets near her udder or to draw them towards her teats, using her forelegs in a scooping action (Fraser, 1974).

Considering the disparity in weight between the sow and her newborn offspring, it may seem remarkable that any of the litter are able to survive damage by crushing but Signoret, Baldwin, Fraser and Hafez (1975) stated that behaviourally, the sow is well equipped to avoid damaging her young; as she generally lies down very cautiously and only after ploughing through the bedding with her snout. They also claimed that many sows are very responsive to the squeals of their young and will soon rise in response to the vocalisations of a trapped piglet. Pomeroy (1960b) likewise observed that the incidence of crushing depended on sow/piglet behavioural interactions and he also mentioned the sow ploughing through the bedding with her snout in order to throw out any concealed piglets before lying down. Most sows lie down slowly and cautiously and he considered that the only stage at which piglets are in any danger is when the sow rolls over onto her side, but even then, a normal and active pig tends to be squeezed out from the curved surface of the sow's side, although a moribund one will be crushed. Neonatal mortality due to such traumatic injuries is discussed further in Chapter 7.

Chapter 2

MECHANICAL ACTIVITY OF THE UTERUS

2.1 Introduction

The uterus is a quite unique muscular organ; it grows for several months during which time it serves its purpose best by being relaxed but then at parturition, it is required to perform a considerable amount of contractile work during a period of a relatively few hours (Fuchs, 1977).

2.2 Histology of the myometrium and effect of this on uterine physiology

From a viewpoint of its mechanical activity, it is the myometrium (the middle layer of smooth muscle in the uterus wall) which is of profound importance. According to Fuchs (1977), the myometrium is composed of long smooth muscle cells in a network of intricately interwoven bundles and this pattern is designed to produce continuous protection for the growing foetus as well as optimal mechanical conditions for its expulsion. Naaktgeboren (1974) described how the smooth muscle cells are arranged in 2 sheets with longitudinal fibres on the outside, circular fibres inside. The size of the myometrial cells depends on the functional state of the uterus and is greatly increased during pregnancy. Russe (1979) agreed, stating that in a non-pregnant mammal, the myometrial cells are 3-5 μ wide and 50-100 μ long, but that this may increase during pregnancy up to 8-10 μ x 100 μ. This increase in size during pregnancy causes changes in the surface area: volume relationships of the cell which affects its physiology. Although myometrial cells are individually

recognisable, they act as a functional syncytium and more than any other type of smooth muscle, the myometrium is able to react to endocrine factors and shows histochemical, histological, ultrastructural and physiological changes so that there are very great differences between the pregnant and non pregnant states (Naaktgeboren, 1974). Nemetschek-Gansler (1967) described the myometrial cells immediately before delivery as resembling those when oestrogen is the dominant hormone; ie. they appear interdigitated whereas there is much less interdigitation under the influence of progesterone. There are also differences in appearance between uteri from normal, quiet animals and those from very anxious or nervous ones and these could account for the differences in functioning which are described later (Carter, Naaktgeboren and Van Zon Van Wagtendonk, 1971).

2.3 Uterine contractions during the farrowing process

In the first stage of labour, the firm texture of the pregnant cervix changes to a soft yielding consistency which allows dilatation as a result of tension created by the contraction of the uterine longitudinal muscle (Arthur, 1975). The propulsion of the foetus into the cervix widens it to the limits of its extensibility and this stretching of the soft tissues of the pelvic cavity initiates a sudden expulsive contraction of the abdominal muscles known as Ferguson's reflex (Ferguson, 1941) which is responsible for propelling the foetus through the vagina and vulva. This reflex may be particularly important in the pig which has a long cervix with a considerable surface area (Forsling, MacDonald and Ellendorff, 1979). In an earlier publication Arthur (1964) described how the initial uterine contractions are limited to those portions of the uterus nearest to the cervix, while the rest of the uterus is quiescent. Marrable (1971) agreed, stating that the most powerful

contractions are applied only to the foetus which is nearest to the cervix and that the contractions mainly involve the longitudinal muscle but that circular muscle is relaxed, which produces a shortening effect and this is important in helping to reduce the amount of stretching of the umbilical cord which has to be undergone by foetuses located at the ovarian ends of the uterus (Benesch and Wright, 1951). These authors also described how the contractions which occur immediately anterior to the foetus nearest the cervix are then either repeated in the other horn or immediately anterior to the one just expelled.

Taverne et al (1976, 1979) used implanted electrodes to study the physiology of uterine contractions in mini-pigs; they found that the uterus was quite active during the last weeks of pregnancy, particularly those areas of the myometrium which were in direct contact with the foetuses, whereas the areas of myometrium between piglets only showed distinct activity after nest building had become evident. Zerobin and Sporri (1972), however, found in their work on the domestic pig that there was very little activity until approximately 24 hours before farrowing and that immediately after let-down of milk to the teats occurred, there was an increase in contraction frequency as parturition approached. The typical pregnancy pattern of myometrial activity only changes between 4-9 hours before the first delivery and there are large differences in characteristics of uterine contractions between individual sows (Taverne, 1982). Taverne et al (1976) reported that during the early stages of parturition, all parts of the myometrium showed the same fairly regular pattern of activity, which alternated with periods of quiescence; later, the contraction frequency increased. Single abdominal contractions were observed just as

the first pig entered the cervix and these had the effect of strengthening uterine activity and thus facilating delivery as did the increased intra-uterine pressure caused by breath holding at the height of inspiration (Zerobin and Sporri, 1972).

Surprisingly perhaps, Taverne et al (1976) found that contractions may originate at any place along the uterine horns and be anti-peristaltic as well as peristaltic. Likewise Naaktgeboren (1974) reported that although contractions usually run from ovary to cervix, they may also pass in the reverse direction. More recent research (Zerobin, 1980) agreed with these findings and demonstrated that, initially, contraction waves travel in both directions but that after the expulsion of the first piglet, they are all tubo-cervical. The uterine contractions are regular and well co-ordinated but a nerve supply is not necessary and, according to Naaktgeboren, every myometrial cell is able to act as a pacemaker, although cells at the top of the uterine horn seem to possess this property to a higher degree than the other cells. This finding is in contrast to that of Kao (1959) in the rabbit who found that action potentials were equally frequent at both ends of the uterus and of Marshall (1959) who claimed to have found pacemaker zones at both ends of the uterus in oestrogen dominated rats.

Spontaneous electrical activity can occur at any point along the uterine horn (Taverne, Naaktgeboren and Van der Weyden, 1979; Taverne, 1982). These authors postulated that the cervico-ovarian directed contractions might prevent the interruption of the foetal- placental- maternal connections which were not yet ready for expulsion. They suggested that when one of the most caudally positioned foetuses has approached the pelvic region,

its presence there initiates a contraction directed up towards the ovarian end of the uterus which, because it favoured the transport of other foetuses in this direction, would tend to safeguard the umbilical and placental circulation of the more anteriorly placed piglets. The authors claimed, however, that despite a considerable retraction of the uterus in those parts which have already emptied, the last piglets have to be transported over a longer distance than the first piglets, which frequently leads to umbilical cord rupture and stillborn piglets.

According to Harvey (1962), the uterine contractions associated with parturition are due to:

a) intrinsic contractility of the smooth muscle which is enhanced by the effects of hormones; and
b) extrinsic autonomic reflexes which are enhanced by foetal motility.

This latter point would mean that a dead piglet in utero would take longer to be expelled which appears to be the case (see Chapter 3).

Myometrial cells are particularly sensitive to stretch stimuli (Naaktgeboren, 1974) and according to Russe (1979), the cells have a certain elasticity which determines the tonus of the muscle so that as the foetus grows, tension develops in the muscle due to this. Contractile cells which have reached their tensile limit become depolarised and contract in order to prevent a rupture by over-extension and these contractions happen spontaneously i.e. they are independent of exogenous stimulation such as hormones. This theory has been confirmed by in vitro investigations using myometrial strips. The volume of the pregnant uterus is important

in determining the onset of parturition and the distension caused by the growing foetuses may contribute to increasing the sensitivity of the uterus to oxytocin and the increase in spontaneous activity near term (Fuchs, 1978). The pregnant horn of a unilaterally pregnant rabbit has a much greater response to oxytocin than the non-pregnant horn and its spontaneous contractions are more frequent. Distension has also been shown to improve impulse conduction in smooth muscle (Daniel, 1960).

2.4 Effect of hormones on uterine motility

i. Oestrogen and progesterone

The contractility of the myometrium is governed by hormones (Russe, 1979) and the principles of parturition in the sow are the same as in other mammalian species in that the mechanism which changes the uterus from a state of withholding the foetus to one of expelling it, is connected with the change from progesterone domination to oestrogen domination (Zerobin and Sporri, 1972). Before parturition, co-ordinated propagation of the contraction waves is not possible as progesterone inhibits the formation and spread of contractions by increasing the membrane potential but this drops under the influence of oestrogen, however, and periodic contractions develop which can propagate themselves.

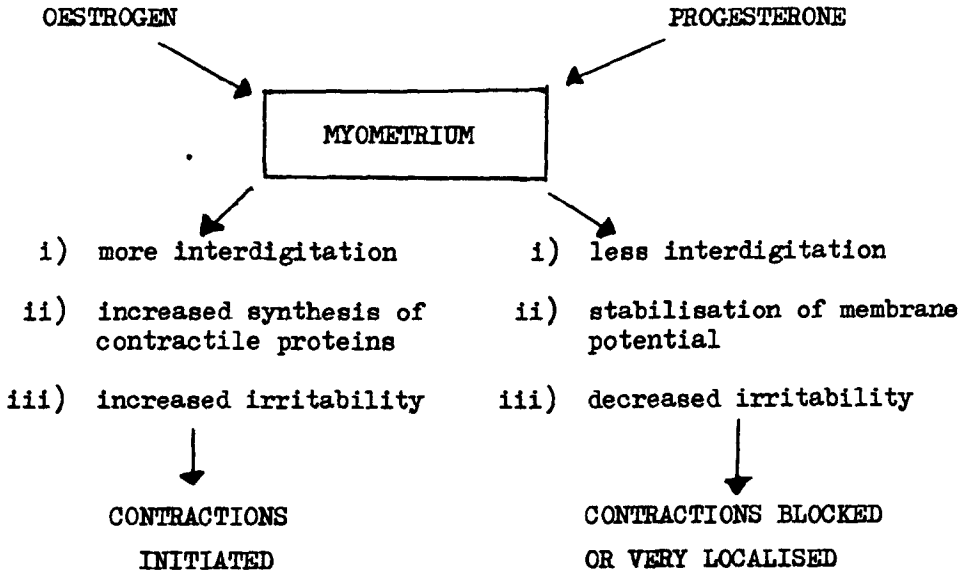
Mention has already been made of the histological changes caused by the ovarian steroids; the interdigitation produced by oestrogen facilitates the rapid propagation of action potentials and Kato (1970) also found that the sex steroids influence the ratio of

actin to myosin and so cause changes in actomyosin. His data suggested that the propagation properties and contractile strength may vary markedly under different hormonal conditions. Russe (1979) described how oestrogens stimulate the synthesis of contractile proteins as well as increasing water absorption and ionic concentration which causes an increase in membrane potential so that the cell becomes irritable and is able to contract. Progesterone, however, stabilises the myometrial cell membrane by increasing the calcium binding and changing the cell's permeability to sodium, so that throughout pregnancy, the myometrium is non-irritable. The threshold needed for any stimulus to cause a contraction is very high and any contractions are very localised; this protects the foetus but the blocking effect has to be removed before the start of parturition. The effect of ovarian steroids on the myometrium is summarised in fig. 2.1.

Work on rats and rabbits has shown that progesterone seems to impair the propagation of contractile activity but that withdrawal of progesterone alone does not ensure the development of synchronous activity e.g. if rats are ovariectomised in late pregnancy, the uterus becomes very active but although it may continue to contract for days, only a few foetuses are expelled occasionally and the 2 ends of the horn may be contracting at different rates. Oestrogen treatment of such animals improves synchronisation (Fuchs, 1978).

Fuchs concluded from her work that the effect of ovarian steroids on uterine contractility is very complex. Spontaneous activity is primarily controlled by oestrogens and withdrawal of these leads to activation of mechanisms generating intrinsic spontaneous

Fig. 2.1 Schematic representation of the effects of ovarian steroids on the myometrium



(after Kato, 1970; Russe, 1979)

activity which is suppressed by high circulating oestrogen levels. Progesterone has similar effects as lack of oestrogens in rats, but in rabbits, when oestrogen is present, progesterone augments the suppression of spontaneous activity. This would agree with Porter (1975) who claimed that oestrogen and progesterone cause an elevated resting membrane potential and thus tend to inhibit contractions.

According to Fuchs (1978), oestrogens increase the excitability of the myometrium whereas progesterone suppresses it. Oestrogens also promote the conduction of contraction waves along the myometrium (hence the results of Naaktgeboren and Carter (1971) who filmed a rabbit uterus just prior to parturition when oestrogen levels are high and progesterone low and who demonstrated an increase in conduction at this time), while progesterone impairs it. Oestrogens appear to be needed for the synthesis of contractile proteins as well as for the enzymes which are involved in the contractile process and so, in this sense, oestrogens stimulate uterine contractility. However, the direct effect of oestrogens is a suppression of the intrinsic myogenic contractions, while progesterone appears to act as an anti-oestrogen.

Uterine quiescence is not a pre-requisite for maintaining gestation, as long as the contractions remain local and non-propagated (Fuchs, 1978). A lack of oestrogens produces this result but since oestrogens themselves are needed to promote the growth of the uterus in order to accommodate the foetuses, the anti-oestrogenic property of progesterone is needed to counteract its co-ordinating

property. Distension of the uterus itself constitutes an ever increasing stimulus for hypertrophy of the myometrial cells and consequently for the contractile force of the uterus to increase. Too strong contractions (even if they are not propagated) could jeopardise the placental blood flow and so the presence of progesterone is needed to diminish the uterine responsiveness to many stimuli which could be excitatory.

The molecular or cellular basis for the opposing effects of oestrogen and progesterone on the conduction of contraction waves along the myometrium and the spread of excitation from cell to cell, remains unknown, but it is likely the myometrial cell membranes and membrane bound calcium are involved (Fuchs, 1978).

ii. Adrenalin and noradrenalin

Much of the research into the effects of these hormones on uterine motility has been carried out on pregnant women but it is likely that the results obtained will apply to the sow as well. The situation is exceedingly complex but the bulk of the evidence suggests that the endogenous release or exogenous administration of catecholamines has an inhibitory effect on the myometrium so that the uterus becomes quiescent (Adams, 1940; Garrett, 1960; Amy and Karin, 1974; Russe, 1979).

The (human) myometrium has both α and β adrenergic receptors and stimulation of the former produces activation whereas stimulation of the latter produces inhibition of smooth muscle activity (Fuchs, 1977). Which effect will be predominant depends on the amount of progesterone present (Shabanah, Toth and Maughan, 1964a);

moderate amounts of progesterone produce an excitatory effect, but large amounts an inhibitory effect. This means that, during pregnancy when progesterone levels are very high, the catecholamines have an inhibitory effect which overrides the stimulatory effect of moderately high oestrogen levels. Just before parturition, however, the drop in progesterone and concurrent peaking of oestrogen produces an excitatory effect. Shabanah, Toth, Carassavas and Maughan (1968) continuing this work, concluded that progesterone in a pregnant animal lowers the threshold of the β inhibitory receptors in their response to catecholamines i.e. myometrial activity is inhibited.

This effect is important as it provides a means by which environmental factors can affect parturition and Shabanah, Tricomi and Suarez (1969b) pointed out that although a pregnant woman (or any mammal) can avoid ingesting harmful chemicals, she (it) cannot avoid the endogenous catecholamines produced under conditions of stress. In dogs, Shabanah, Toth and Maughan (1965) showed that strong emotional stress always produced some inhibition of uterine activity which could be prevented by the use of sympatholytic drugs while Taverne et al (1979) using mini-pigs, reported that myometrial activity was affected by non-specific environmental stimuli such as sounds emanating from an adjacent room or the entrance of a person into the room containing the mini-sow. Naaktgeboren (1972b) recorded uterine activity in situ by using the open end catheter method or by recording myometrial activity and he showed that psychogenous influences such as anxiety are able to change the pattern of myometrial activity.

iii. Acetylcholine

Acetylcholine has the effect of increasing myometrial activity and there is also an interaction of acetylcholine with sex steriods, in that oestrogen activates the synthesis of acetylcholine whereas progesterone causes a drop in acetylcholine activity, so that the catecholamines can manifest their effects (Shabanah et al, 1964b).

iv. Oxytocin

The stimulatory effect of oxytocin on uterine motility has been recognised for many years e.g. over 40 years ago, Adams (1940) experimenting on myometrial strips in vitro demonstrated increased contractions when pituitrin was administered and the sensitivity of the myometrium to pituitrin was particularly high in pregnant uteri. The stimulatory effects of oxytocin on uterine motility appear to be due to its ability to initiate spike discharges as well as increasing the frequency and prolonging the duration of each discharge (Kao, 1967). Soloff and Swartz (1974) found that radio-active oxytocin was bound by the sow uterus with a great affinity and on the basis of their results, they proposed the presence of specialised receptors on the myometrial cell membranes. It has been reported that (in rabbits) oestrogen treatment increases the number of oxytocin receptors, while progesterone treatment decreases it (Nissenson, Flouret and Hechter, 1978). In 1979, Porter proposed a hypothesis in which progesterone inhibits the formation of oestrogen receptors in the pregnant myometrium and so prevents oestrogen from increasing the number of oxytocin receptors. As progesterone declines near to parturition, the effects of oestrogen become manifest and the myometrium increases in sensitivity

to oxytocin as the number of oxytocin receptors rises. These changes (which would normally be expected to lead to increased spontaneous activity) occur under the protective influence of relaxin, which in turn has the effect of restraining spontaneous muscle activity but leaving the uterus capable of responding to oxytocin. These effects produce a state of extreme responsiveness so that when the signal is given, this overrides the relaxin inhibition and the highly co-ordinated birth process can start.

There is a well recognised relationship between oxytocin and the catecholamines which means that the latter can antagonise the effect of oxytocin on uterine motility (Hays and Van Demark, 1953; Naaktgeboren, 1972b). This in turn could give rise to protracted farrowings or even uterine inertia and stillbirth and any inhibition of oxytocin release will also affect the milk ejection process (Cross, 1955a, 1955c; Martin and McDowell, 1975).

2.5 Relationship between uterine motility, hormone changes and sow behaviour during the farrowing process

Taverne et al (1979) reported a fall in progesterone levels and a rise in oestrogen approximately 12-24 hours before the birth of the first piglet which coincided with behavioural changes such as nest-building although the myometrium was no more active than it had been before, with the electromyogram (EMG) showing irregular episodes of prolonged phases of activity in parts of the uterine horn which contained a foetus, but not in others. It was only between 4-9 hours before the first delivery that the EMG pattern changed and myometrial activity increased; likewise there was an increase in the oxytocin concentration of peripheral plasma.

During the last 3 hours before delivery, sows became laterally recumbent and there was evidence of straining (also of abdominal discomfort and general restlessness according to English et al, 1977) which showed as increased electrical activity on the EMG. After the onset of straining and during the delivery of the piglets, the mean frequency of electrical discharges increased (denoting maximal myometrial activity) and oxytocin concentration reached its peak value. During this expulsive phase, there was a wide range of oxytocin concentrations which the authors proposed could be related to the variable lengths of time necessary for the passage of individual piglets through the pelvic canal. Forsling, Taverne and Ellendorff (1977) reported that oxytocin was not secreted continuously but rather, in a series of spurts. One of their experimental mini-pig sows had a prolonged farrowing extending over 8 hours and oxytocin levels remained high over this period, which the authors took to indicate that there must be a considerable reserve of material in the maternal pituitary.

2.6 Effect of contractions on uterine blood flow

According to Dawes (1968), uterine contractions result in compression of the myometrial blood vessels and so reduce uterine blood flow. Likewise, Greiss and Anderson (1968) observed uterine blood flow patterns during labour in a range of species and concluded that the amount of blood flow varied inversely with the myometrial contractions. Since myometrial activity increases progressively during labour, the uterine blood flow decreases progressively which the authors claimed meant that parturition is inherently stressful to the foetus and any complications or deviation from the normal sequence

of events may be sufficient to compromise the foetus.

The characteristic relationship between contractions and uterine blood flow during labour has been described in the human by Brotanek, Hendricks and Yoshida (1969). Each contraction is preceded by an initial decline in blood flow but this is then followed by a partial or complete recovery in the early contractile phase. A second fall in blood flow occurs as the intra-uterine pressure reaches about 30 mm Hg and continues until the peak of the contraction. Recovery of the blood flow follows the completion of the contraction.

From their work on Rhesus monkeys, Lees, Hill, Ochsner, Thomas and Novy (1971) proposed 3 methods by which uterine blood flow could be impeded:

a) Vasomotor influences (e.g. adrenalin - see below) which are independent of myometrial contractions.
b) Occlusion of myometrial vessels by direct mechanical compression.
c) Increase in intra-amniotic pressure which may compress the uterine veins while a slightly higher pressure will compress the intervillous spaces.

Any reduction in uterine blood flow due to contractions might be expected to cause hypoxia of the foetus and several workers have indeed noted a significant fall in foetal arterial oxygen saturation during strong uterine contractions, even though the umbilical cord and placenta were still intact (Dawes et al, 1960; Dawes, 1961; 1968).

In lambs, it appears that a very severe (i.e. more than 50%) reduction in uterine blood flow is necessary to affect the foetus to any significant degree due to various compensating mechanisms which assist the foetus in withstanding a transitory reduction in oxygen supply (Assali, Holm and Sehgal, 1962). One of the mechanisms employed by the foetus was to increase blood flow through the umbilical vessels so that a reduction of uterine blood flow to less than half control values for 3-4 minutes only evoked a slight bradycardia in the foetus although when flow was reduced further, heart rate decreased markedly; these changes subsided rapidly when normal uterine blood flow was restored.

2.7 Effect of hormones on uterine blood flow

Uterine blood flow is insensitive to acute changes of respiratory gases caused by maternal hypoxia which suggest that oxygen tension is not an important regulator of uterine blood flow, rather, hormonal regulation is the main mechanism (Meschia and Battaglia, 1972).

i. Catecholamines

In addition to being affected by the myometrial contractions, uterine blood flow is also affected by various hormones such as the catecholamines adrenalin and noradrenalin which are potent arterial vasoconstrictors (Ahlquist, 1950; Misrahy, Beran, Spradley and Garwood, 1960; Greiss, 1963; Carter and Olin, 1972). Using rabbits and guinea pigs, Dornhorst and Young (1952) demonstrated that the placental blood vessels are very sensitive to catecholamines but that the foetus is relatively insensitive. When small doses of catecholamines were administered to pregnant animals of these species, this caused impairment of the placental circulation with

a subsequent slowing of the foetal heart rate and a fall in foetal blood pressure. They claimed that this foetal response to adrenalin in the maternal circulation is due to a reduction in the blood supply to the maternal side of the placenta and consequent asphyxia of the foetus. When oxytocin was present in the maternal circulation, although it causes strong uterine contractions, there is little impairment of foetal and placental blood flow which, the authors proposed, is indicative that the catecholamines have a direct vasoconstrictive effect on the uterine blood supply and do not exert their effects indirectly by causing decreased contractility. (They also found no evidence of transfer of catecholamines from mother to foetus).

Bell (1972) also stated that the uterine arterial vasculature is constricted by catecholamines and if this occurred frequently, it could interfere with the development of the foetuses. He claimed in addition, that stress in pregnant mammals has been demonstrated to be associated with a fall in pregnanediol excretion which is suggestive of a reduced placental blood flow. More evidence concerning the deleterious effects of catecholamine action in pregnant animals was provided by Shabanah, Tricomi and Suarez (1969a) who administered adrenalin to pregnant does in late gestation and observed that the vaso-constriction produced caused retarded foetal growth in 79% of the litters and premature labour in 29%. Likewise Auletta (1971) showed a significant reduction in implantation and foetal survival after rabbits had been injected with adrenalin which he speculated was due to vaso-constriction of the uterine vessels causing hypoxia.

Under normal conditions, the uterus is able to provide an adequate ratio between oestrogen and progesterone but if, however, there is an imbalance of autonomic hormones, this can adversely affect uterine functioning and this is especially true at certain critical stages of foetal development (Shabanah, Tricomi and Suarez, 1969b). Long lasting sympathetic nervous system hyperactivity (either emotionally or artificially induced) interferes with the utero-placental blood flow. Depending on the time of onset and duration of this, the result may vary from a blighted ovum to foetal death, from a malnourished to a premature neonate or from abortion to premature labour, as the catecholamines cross the placenta and affect both maternal and foetal blood vessels. (The different placental types of the species used may help to explain the differences in transplacental transfer of catecholamines in this work and that of Dornhorst and Young above).

Mention has been made above of the fact that catecholamines can cause foetal asphyxia due to their vasoconstrictive properties. In Rhesus monkeys, Adamsons, Mueller-Heubach and Myers (1971) found that both adrenalin and noradrenalin produced a state of severe foetal asphyxia when they were administered to dams in sufficiently large amounts to elicit a distinct increase in maternal blood pressure.

ii. Acetylcholine

The main uterine arteries in the sow contain a plexus of acetylcholinesterase positive nerves which suggests that the parasympathetic nerves are involved in regulating uterine arterial diameter (Bell, 1972). He also claimed that it has been demonstrated

in the pregnant guinea pig sow that acetylcholine caused dilation of the uterine arteries.

iii. Oxytocin

Due to its action in increasing muscle tone, oxytocin has the effect of decreasing placental blood flow and so may lead to foetal hypoxia (Misrahy et al, 1960).

2.8 Effect of the autonomic nervous system on the products of conception

Much of the research on this topic has been carried out by Shabanah and his colleagues e.g. Shabanah, Toth and Maughan (1964a, b); Toth, McEwen and Shabanah (1964). The latter authors suggested that the balance between the 2 branches of the autonomic nervous system determines the condition of the uterine blood vessels (i.e. it regulates the amounts of nutrients and gases which are delivered) and an imbalance between the 2 branches (as with sympathetic dominance during psycho-social stress) could severely impair foetal development. The authors carried out pelvic parasympathectomy in pregnant dogs which resulted in total foetal death and resorption. They hypothesised that these results indicated diminished utero-placental blood flow, which reduced the amount of transferable nutrients and produced hypoxia, which in turn decreased the permeability of the utero-placental barrier and so on. The stress of labour on the mother may also cause the release of hormones from the adrenal gland so that uterine blood supply is reduced as Koleta (1967) claimed is the case in women. In his investigations, he noted that labour stress caused a reduction in the number of

circulating eosinophils to only 13% of the level found during the last week of pregnancy. He also claimed that the effects of the maternal stress response diminish the volume of maternal blood circulating in the placenta and this diminution will be aggravated with the increasing duration of labour and will tend to produce foetal hypoxia.

2.9 The effect of maternal exercise on the products of conception

The effects of severe exercise in heavily pregnant ewes have been investigated by Orr, Ungerer, Will, Wernicke and Curet (1972) who concluded that uterine blood flow is not impaired and that such exercise in a healthy animal is not hazardous. Similarly, in a later investigation, Curet, Orr, Rankin and Ungerer (1976) trained pregnant ewes on a treadmill for 3 weeks and found that the total uterine blood flow was not changed following exercise but that its distribution was altered in favour of the placenta and they hypothesised that this represented a compensatory mechanism for the foetus after a period of exercise.

With reference to the foetus itself, Emmanoulides, Hobel, Yashiro and Klyman (1972) concluded from their work on sheep that moderately severe maternal exercise may be detrimental to foetuses which have a compromised umbilical circulation, but that normal foetuses tolerate exercise well. Also using sheep, Clapp (1980) reported that sustained exercise to the point of maternal exhaustion was not immediately detrimental to the foetus, despite a fall in uterine blood flow and foetal pO_2. Although maternal blood lactate increased, there was no excess lactate production by the utero-placental tissues or the foetus. In

contrast, however, Longo, Hewitt, Lorijn and Gilbert (1978) examined the effect of maternal exercise on foetal oxygenation and uterine blood flow in pregnant ewes and concluded that "moderate" to "heavy" exercise can result in significant foetal hypoxia and may cause intra-uterine growth retardation due to decreased uterine blood flow.

In pregnant women, Muller-Tyl, Salzer and Mick (1976) investigated the effects of gymnastic exercises and found that the state of the gymnast's babies (i.e. babies of women who had undergone exercises) one minute after birth was better than those in the control group (i.e. they needed less resuscitation after birth). The birth weight in the exercise group was also higher, although not significantly. Other studies have attempted to correlate the physical fitness of pregnant women near term with various blood characteristics at delivery (Errkola and Rauramo, 1976). These workers found that fit mothers had a higher blood pH after delivery than the unfit mothers. The authors proposed that the higher pH in the infants from fit mothers could either be due to a lower concentration of acid metabolites in the mother, which would be transferred across the placenta, or to a better blood circulation in the uterus and placenta which would produce a more efficient elimination of carbon dioxide from foetal blood. They also quoted umpublished results which showed that placentae of fit women are significantly heavier than those of unfit women. Other workers have also reported a lower production of lactate during delivery in women who have followed a gymnastic programme during pregnancy compared with sedentary women (Stembera, Hodr and Friendlandrova, 1961).

By way of contrast, however, Ihrman (1960) found no differences in blood parameters such as total haemoglobin concentration, total blood volume etc. between exercised and control groups of pregnant women. He claimed that the state of pregnancy is characterised by a circulatory adjustment which cannot be influenced in any important way by physical exercise and he concluded that the greatest value of exercise is in promoting relaxation at delivery.

As a result of his work monitoring uterine motility in sows, Zerobin (1980) concluded that free movement before farrowing aids farrowing performance as shown by his intra-uterine pressure tracings.

In conclusion, there has been relatively little work carried out to determine the effects of maternal exercise on uterine activity and blood flow or foetal well-being. There is the additional problem of little quantification of the exercise carried out as well as the difficulty of trying to relate the degree of exercise undertaken in one species to that in another. In general, it would appear that foetal well-being is only adversely affected when the maternal exercise is severe and that slight or moderate exercise is beneficial in terms of a lowered concentration of acid metabolites in foetal blood both during and after parturition.

Chapter 3

DURATION OF FARROWING

3.1 Introduction

From reports in the literature, this appears to be very variable and the situation is further complicated by the fact that many authors do not specify their criteria for the beginning and end of the process; the start of farrowing is usually considered to be the delivery of the first piglet while the process ends with the delivery of the last piglet - knowledge which is only gained in retrospect with the expulsion of the placenta.

3.2 Recorded farrowing times

Many observations have been made on the duration of farrowing in pigs which indicate the extremely variable periods of time involved (table 3.1). Most farrowings take between 200-300 minutes although some are considerably longer.

Table 3.1 Observations on the duration of farrowing

Author	Year	No. sows	Duration of farrowing (min)
Arthur	1964		Approx. 240
Baldwin	1969		Sows 180, gilts 240
Bourne	1969b)	5	125-205
Bourne	1971a)	9	80-210
Cavalcanti et al	1979		Mean times 278-355
DeRoth & Downie	1976	16	Mean 186, range 87-340
Dinu et al	1978		Mean 165
Fahmy & Friend	1981	92	Mean 288 (30-1350)
Fraser	1974		Approx. 180
Friend et al	1962	212	60-990
			80% < 360
			18% 360-720
			2% > 720
Hendrix et al	1978	40	Mean 257

Jones	1966b)	40	28-535, mean 173
Krehbiel et al	1968		Mean 160
Linnemann et al	1976	98	Mean 260
Marrable	1971	67	24-534, mean 174
Michelat	1966		Very variable, may extend to 4320
Randall	1968	30	83-630, mean 203
Randall	1972a)		30-630, mean 156
Schafer	1941	90	Over 74% in < 240
Scheel et al	1977	14	Mean 206
Seiciu et al	1979	121	41-519
Smith	1937	23	53-1080, mean 259(including expulsion of placenta)
Sommer	1979	52	Mean 246 (5% < 120, 17% > 480)
Swift	1968	1	2310

3.3 Mean birth intervals

It might be expected that the duration of farrowing would depend upon the size of the litter to be born but most authors have reported no direct relationship between litter size and farrowing duration (e.g. Janssen, Libal and Wahlstrom, 1973; Seiciu, Paraigan, Penciu and Volinturi, 1979). Typical results are those of MacDonald, Holness and Moxley (1963) and Friend, Cunningham and Nicholson (1962) which are shown in table 3.2.

Table 3.2 Relationship between duration of farrowing and litter size

Author		Litter size	Mean duration of farrowing (min)
Friend et al	1962	9 or less	310
		10-12	290
		13-15	286
		16 or more	352
MacDonald et al	1963	9 or less	278
		10-12	268
		13-15	299
		16 or more	272

According to Fahmy and Flipot (1981), there is a curvilinear relationship between duration of farrowing and litter size with the shortest farrowing times occurring in sows with medium sized litters and they suggested that prolonged delivery of small litters could be due to the heavier birth weights of these piglets.

Randall (1972a) considered that the mean interval between successive births in a litter is a better criterion for the duration of farrowing than the total time taken and several authors have used this parameter (table 3.3). It can be seen that there is general agreement in the literature over a mean birth interval of approximately 15 minutes, although birth intervals tend to be longer at the start and end of farrowing.

Table 3.3 Estimates of mean birth intervals

Author	Year	No. litters	Mean interval between successive births (min.)
Andreasson & Svendsen	1979		16 between livebirths 42 between live & stillbirths
Bourne	1969b)	5	16.9
Bourne	1971a)	9	8.0 - 21.2
DeRoth & Downie	1976	16	16
Dinu et al	1978		15-20
England et al	1976	103	20 (2nd-3rd birth) 13 (11th-12th birth) 20 (15th-16th birth) 10 (17th-18th birth)
Fahmy & Flipot	1981	19	15.7
Fraser	1974		15
Janssen et al	1973	30	17 (between livebirths) 47 (between livebirths & stillbirths)
Jones	1966b)	40	Range 1-230, mean 15.3 (long intervals between 1st & 2nd and before last pig)

Randall	1968	30	Range 6.9-51.9, mean 17.6 39.6 (1st-2nd) 27.7 (penultimate-last)
Randall	1972a)	103	Range 4-48, mean 16 (long intervals between 1st-2nd and before last pig)
Sprecher et al	1974		13-18 (between livebirths), 45-55 (between live & stillbirths)
Stanton et al	1973		Longer at start & end of litter than in middle
Taverne et al	1977		14.6 (pigs from same horn) 11.8 (pigs from different horn)
Walters	1965	25	15.9

3.4 Effect of drugs and hormones

i. Drugs

a) Parasympathomimetics

Most of the work investigating the effect of drugs on the duration of farrowing has been concerned with investigations into the action of parasympathomimetics such as neostigmine. As their name suggests, these act on the parasympathetic nervous system to inhibit the action of cholinesterase and so to delay the breakdown of acetylcholine which instead continues to function as a chemical transmitter conveying impulses from nerves to muscle. This means that when a parturient sow is given neostigmine, the uterus undergoes stronger contractions and so the farrowing process is accelerated (McInnes, 1979). In his first trial, McInnes injected 100 sows with 5 mg neostigmine methylsulphate after they had produced either 1 or 2 piglets, while 141 sows were left untreated and acted as controls. The mean duration of farrowing for the treated sows was 146 minutes compared to 281 minutes for the controls. In addition, there seemed to be

advantages in terms of piglet survival, both at and after birth, and McInnes proposed that the reduction in farrowing time meant less likelihood of hypoxia during the birth process and also an accelerated intake of colostrum (table 3.4).

Table 3.4 Effect of neostigmine on duration of farrowing and piglet survival

	Treated sows (+ neostigmine)	Controls
Trial 1 (100 sows)		
Mean duration of farrowing	146 min	281 min
Born alive	97.2%	93.9%
% survival in first 48 hours	94.7%	89.4%
Trial 2 (500 sows)		
Born alive	97.0%	94.0%
% survival in first 48 hours	94.5%	89.5%
% survival to weaning	84.0%	78.0%

(from McInnes, 1979)

Cropper, Leman and Diehl (1975) also found that the administration of neostigmine caused a reduction in mean birth interval, while Hendrix, Kelley, Gaskins and Hinrichs (1978) investigated the effect of administering neostigmine and removing the piglets at birth. The mean farrowing times were as follows: untreated sows 257 minutes, sows with piglets removed at birth 338 minutes, sows injected with neostigmine plus piglet removal 392 minutes. The duration of parturition in the neostigmine group is considerably longer than would be expected, possibly due to the other factors involved such as stress resulting from piglet removal.

With reference to other parasympathomimetics, Bjorklund (1981) reported that the administration of dichlorvos caused a reduction in mean birth interval from 16 to 11 minutes while

Leman and Sprecher (1976) claimed that the administration of carbacholine significantly reduced the mean birth interval from 16.5 to 10.5 minutes in one trial and from 21 to 14.5 minutes in another. In both these trials, carbacholine was injected after the first pig had been delivered whereas in a later trial it was not injected until the birth of the third or fourth pig and there was no effect on birth interval.

b) Other drugs

When administered to rats, aspirin and indomethacin have been shown to prolong parturition and increase the stillbirth rate, possibly via the inhibition of prostaglandin release (Aiken, 1972).

ii. Hormones

a) Prostaglandins

There is no clear agreement in the literature as to the precise effects of prostaglandins on duration of farrowings. Diehl, Godke, Killian and Day (1974) found no significant reduction in farrowing time with prostaglandin $F_{2\alpha}$ compared with a saline control, whereas Downey, Conlon, Irvine and Baker (1976) reported that the use of a prostaglandin analogue gave rise to prolonged farrowings (414 minutes v. 210 minutes for control sows). Bjorkund (1981), however, quoted results from Swedish work which indicated that the administration of prostaglandin caused a reduction in farrowing time.

b) Oxytocin

This has the effect of decreasing the duration of farrowing (Pejsak and Tereszcuk, 1982) and table 3.5.

Table 3.5 Effect of oxytocin on duration of farrowing

Treatment	Mean duration of parturition (min.)
a) 1 injection 25i.u. oxytocin	150
b) slow drip 0.125i.u./min. until end of farrowing	220
c) treatments a) + b)	89
d) untreated control	239

results of treatments c) & d) differ significantly ($P < 0.005$)

(from Brenner, Schulze and Gurtler, 1979)

c) Progesterone

Administration of progesterone leads to prolonged farrowings (Minar and Schilling, 1970).

d) ACTH

Injection of 30-60 i.u. ACTH on day 110 of pregnancy caused a reduction in farrowing time in Danish Landrace and Pietrain sows (Ludvigsen, 1982) which is to be expected considering the central role of ACTH in the initiation of parturition.

3.5 Effect of exercise

There is some evidence in the literature to suggest that lack of exercise during pregnancy can lead to a prolongation of the birth process and this applies in humans as well as sows. With reference to the former, Klaus and Noack (1961) stated that athletic women have quick and easy deliveries and in his survey of a large number of Hungarian atheletes, Erdelyi (1962) reported that the duration of labour in these women was shorter than that in women who had taken little exercise in 87% of the cases. In fact, the duration of the second stage of labour was only half the time in athletes as compared with non athletes and

the former also had fewer complications in pregnancy. He suggested that exercise strengthened the abdominal musculature which is beneficial during the second stage of labour; he also thought it likely that there was a greater elasticity of the muscles of the pelvic floor and perineum in athletic women. Anon (1974) agreed that moderate exercise in pregnancy has a beneficial effect on the duration of labour.

Even in dogs there appears to be a link between lack of exercise and an extended parturition as Freak (1962) observed a tendency in bitches for uterine inertia to occur in "those animals of a lazy disposition which disliked exercise and were unwilling to take any during pregnancy".

Similarly in sows, lack of exercise during pregnancy is thought to cause or contribute to primary uterine inertia and a prolonged farrowing, according to Ringarp (1960) who quoted work by Stoss in 1944. Ringarp claimed that farrowing crates prevent sows from taking exercise and so reduce intestinal peristalsis which is a contributory factor in prolonged farrowings. Likewise, Benesch and Wright (1952) stated that lack of exercise in pregnant sows can cause weak labour and other workers have observed cases of inertia more frequently in animals which were closely confined and lacked exercise (Roberts, 1971). There is also a widespread belief that if sows are put into crates more than a week before farrowing, this can lead to problems of constipation and prolonged farrowings (Anon, 1971).

Swedish observations on 650 sows which were loose housed in pens at farrowing indicated that 2.3% of these had a farrowing time in excess of 5 hours, while the figure for 1250 confined farrowing sows was 5.4%, confinement being the only variable factor (Ekesbo, 1981b). Other observations of sows on trial at a Swedish experimental station where tethered sows were released for a period lasting approximately 2 days pre partum to 3 days post partum have been carried out by Andersson (1978). He claimed this practice resulted in considerably less stress for the sows, a shorter farrowing, lower piglet mortality and a much reduced incidence of retained placenta. Similar work has shown that sows which are continually tethered have a prolonged farrowing period which can lead to increased morbidity, particularly in herds which are prone to the mastitis-metritis-agalactia syndrome (Anon, 1979a). Observations of farrowing times when sows were in crates (65 x 200 cm) or in groups in pens (525 x 360 cm) have shown a highly significant reduction in farrowing time with the latter animals (7.2 hours v. 4.6 hours), as well as a significantly lower intra-partal stillbirth rate (5.3% v. 3.6%) in the penned sows (Svendssen and Andreasson, 1980). Similar results have been obtained by Sommer (1979) who kept 13 "old" sows under conditions of group and individual housing. There was a significant ($P < 0.01$) reduction in farrowing time in the group housed animals (192 v. 306 minutes) and also a decrease in the stillbirth rate (4% v. 6% in the individually housed sows) although this was not significant. Observations carried out

on 19 "young" sows which were individually or group housed showed that 16% of the former needed manual assistance during farrowing compared to only 6% of the latter. (Surprisingly, perhaps, the stillbirth rate in the group housed sows was higher than that in the individually housed animals, being 4% v. 3% respectively!) Although there was little difference in numbers of individually and group housed sows farrowing in under 120 minutes (21% v. 19%), the figures for sows taking longer than 480 minutes varied considerably between the 2 groups, being 26% for individually housed sows v. 6% for group housed animals. Backstrom (1973) also investigated the effect of lack of exercise on the duration of farrowing and obtained the following results for herds with more than 10 sows (table 3.6). It is possible that Backstrom's results also indicate the effect of stress on duration of farrowing, as confinement of sows pre-partum has been shown to act as a stressor (see section 3.6).

Beneficial effects of exercise have been claimed by Hale, Booram and McCormick (1981) who reported shorter farrowing times when sows and gilts were made to exercise for 15 minutes daily, 5 days a week for approximately 100 days throughout gestation, although the differences were non significant.

Table 3.6 Effect of exercise on duration of farrowing

Pregnancy treatment	Allowed exercise				No exercise			
	Free in pen		Confined		Free in pen		Confined	
Farrowing treatment	Free	Crate	Free	Crate	Free	Crate	Free	Crate
% sows with a farrowing time > 8 hours	2.3**	3.2	11.7	2.8	3.5	3.5	4.4	5.4**

** difference between treatments is statistically significant ($P < 0.01$)

(from Backstrom, 1973)

3.6 Effect of stress and psychological factors

The subject of stress is considered in more detail in chapter 10 but there are numerous reports in the literature of the links between various psychological factors such as anxiety and stress and the duration of labour which will be considered at this stage. In women, Burns (1976) found a direct correlation between plasma ACTH levels and duration of labour while Garcia (1955) showed a positive relationship between emotional state (as measured by adrenalin levels) and the duration of labour; the birth process being longer in more anxious women. A significant correlation between anxiety, plasma adrenalin level and reduced uterine contractility has been reported in women by Lederman, Lederman, Work and McCann (1978), while higher plasma cortisol levels were also associated with a longer labour. Other workers who have reported a positive relationship between a state of anxiety and a prolonged labour are Kapp, Hornstein and Graham, 1963; Davids, DeVault and Talmadge, 1961; McDonald and Christakos, 1963.

Observations which were carried out on a group of women for signs of any psychological or obstetrical complications during pregnancy and birth revealed that uterine inertia and foetal asphyxia are significantly correlated to emotional attitudes and reactions during pregnancy (Engstrom, Geijerstam, Holmberg and Uhrus, 1964) (table 3.7).

Table 3.7 Relationship between physiological and psychological disorders during pregnancy and birth in women

Type of woman	Incidence of foetal asphyxia	Incidence of uterine inertia	% women with 1 or both conditions
Emotionally stressed	36%	26%	57
Emotionally normal	17%	7%	24

(from Engstrom et al, 1964)

In some women psychological stress (such as the thought of an injection) can interrupt uterine contractions and suppressed fear can also cause a prolonged inhibition of contractions (Garrett, 1960). Likewise, disturbance, anxiety and other psychological factors may cause a severe change in the pattern of uterine activity (Naaktgeboren, 1972). According to Zerobin and Sporri (1972), psychological factors can lead to uterine dystocia; they referred to the work of Condrau (1960) to show that fear can cause muscle tension which may then lead to prolonged parturition. They also cited Walser (1965) that the origin and conduction of pain in other animals is similar to that of humans, although they admitted that it is not known if the labour pains in other species such as the sow are as intense as they are in humans.

With reference to stress caused by a change of environment in the parturient woman, Friedman (1975) observed that in some cases the stress of leaving home and going to hospital for the delivery may result in a total inhibition of uterine contractions.

Similar results have been obtained for other species as the work of Naaktgeboren and Bontekoe (1976), Bontekoe, Blacquiere, Naaktgeboren, Dieleman and Willems (1977) shows. These authors investigated the effects of various stressful stimuli (particularly environmental disturbance) and adrenalin administration in pregnant and parturient rabbits and ewes. They concluded from their results that when plasma oestrogen levels are low, the administration of various stressors or adrenalin produces increased uterine motility, but in a parturient animal with high oestrogen levels the same stimuli inhibit uterine motility so that the process of parturition is blocked. Since similar results were achieved with the use of stressors and adrenalin, Bontekoe et al postulated that the inhibitory effects are mediated by a stress induced activation of the sympathetic nervous system, leading to a release of adrenalin from the adrenal medulla. Similar results were obtained in 1979 by Bosc and Nicolle using rats; a strong stress (injection of formalin) applied after the birth of the first offspring caused a very extended parturition in normal rats, but only a slight increase in adrenalectomised rats. Bontekoe et al disagreed with the hypothesis of Porter and Schofield (1966) that stress may cause a disturbed release of oxytocin leading to labour inertia, since this does not explain the occurrence of stress induced activation of uterine motility during pregnancy.

A temporary cessation of effective labour has been described when parturient mice were moved from one environment to another and back again every one or two hours (Newton, Foshee and Newton, 1966a). The 2 environments used were the familiar cage and a

glass bowl containing bedding impregnated with cat urine. In addition to a prolonged labour, the authors also noted that more mice were born into the familiar environment than into the unfamiliar one. As a result of their work, they suggested that environmental factors play an appreciable role in influencing the course of labour, as the parturient mice seemed to be able to control their labour in order to try to ensure that their offspring were born into familiar surroundings. In another experiment (Newton et al, 1966b), the investigators set up 2 experiments in which mice were disturbed after the birth of their 2nd, 3rd and 4th offspring; the disturbance constituted the dam being held in the investigator's cupped hands for 1 minute which represented a total change in the visual, tactile and olfactory environment. The first experiment used mice which were unaccustomed to handling, whereas the second involved mice that had been handled previously. In both experiments the disturbed mice had a longer labour but there were no differences between "handled" and "non-handled" mice in the first and second experiments. From their results, Newton et al (1966b) concluded that the duration of parturition is at least partly under the control of the central nervous system (as the disturbed group underwent a longer labour). They stated that there are 3 currently recognised motor mechanisms which appear to influence duration of labour and as all of these have some components which are influenced by central nervous system activity, they may easily be affected by environmental disturbance. The first of these is the"bearing down" response i.e. the vigorous contraction of the abdominal

muscles. The authors suggested that there was a voluntary component in straining and that it was this which was affected by environmental disturbance. The second mechanism involved in labour is the complex uterine response which varies according to the hormonal state of the uterus, however the general effect of adrenalin on a parturient uterus is to inhibit any muscular activity. The final mechanism involves additional uterine contractions which are triggered by the gentle stimulation of the lower genital tract. The authors suggested the use of the term "foetus ejection reflex" and they hypothesised that, unlike the milk ejection reflex, this is sensitive to influences from the cerebral cortex and so it can be easily inhibited.

Later, Newton, Peeler and Newton (1968) went on to demonstrate that environmental disturbance significantly influenced the time of arrival of the first offspring as well as offspring mortality. Mice which had been disturbed took longer to give birth to their first offspring and they showed uterine inertia resulting from prolonged labour. Similarly in the bitch, Bleicher (1962) reported that various environmental disturbances (loud noises etc.) delayed parturition but labour resumed after the disturbance ended and the dam became calm again.

There are also similar reports in sows; Naaktgeboren (1979) described the inhibition of labour in a miniature pig sow which had started nest building and had developed normal uterine activity for the first stage of labour. The sow was then removed to another pen which only took a few minutes, but the uterus remained quiescent

for almost 2 hours. Naaktgeboren suggested that the reason for such a mechanism is that once myometrial activity stops, the labouring female can flee if she is disturbed, in other words it is a protective mechanism. He also noted that exogenous or endogenous adrenalin has the same effect.

With reference to the immediate farrowing environment, Peo (1960) speculated that prepartal stress due to the relatively barren restraining environment of the farrowing crate may be associated with prolonged parturition and problems in lactation. He suggested that in a traditional farrowing crate, the sow cannot build a nest and so she becomes confused and frustrated, which usually leads to her struggling in an attempt to escape from the crate. He speculated the effect of this on farrowing performance and concluded that at the best it would not be good, and could result in the delivery of stillborn piglets due to asphyxia following a prolonged farrowing in an exhausted and weakened sow. Peo thought it likely that the sow's lactation performance could be affected due to the possible bruising and lacerations suffered by the udder in her attempts to escape.

More recently, Baxter and Petherick (1980) described a stress reaction in farrowing sows confined to crates. They quoted Cross (1955b) that adrenalin production inhibits oxytocin release and also Chard (1974) that oxytocin is needed to stimulate uterine contractions during labour, so that stress prior to or during labour will have an adverse effect; likewise Porter and Schofield (1966) showed that emotional stress prolonged and delayed labour in rabbits.

3.7 Effect of other factors

i. Breed

Several authors have observed an effect of breed on farrowing time (table 3.8) although the significance of these differences is not apparent; other workers (e.g. Backstrom, 1973) have not been able to obtain any conclusive data.

Table 3.8 Effect of breed on duration of farrowing

Author	Year	Breed	Mean farrowing duration (min)
Cavalcanti	1979	Duroc	355
Barbosa and		Hampshire	353
Sampaio		Landrace	340
		Large White	278
Schafer	1941	Berkshire	< 240
		German Landschwein	33% > 240
			Mean birth interval (min)
Smith	1961	Large White	16
		Berkshire	23
		L.W. x Berks.	13

ii. Disease

Disease may also affect duration of farrowing as Ringarp (1960) reported that 86.7% of control sows farrowed in 1-5 hours but 42.9% of sows suffering from agalactia toxaemia farrowed in 5-8 hours and the difference was very highly significant.

iii. Age

There appears to be a well defined relationship between length of farrowing and sow age (table 3.9) although the effect of parity is not always significant (e.g. Fahmy and Friend, 1981).

Table 3.9 Effect of age on duration of farrowing

Author	Year	Age of animal	Duration of farrowing
Backstrom	1973	Gilts	2.5% > 8 hours
		5th parity and older sows	4.7% > 8 hours

Dinu et al	1980	Gilts	150 min
		4th parity and older sows	235 min
Fiedler, Siler and Volek	1982	1st parity	275 min
		2nd parity	281 min
		3rd parity	284 min
		4th parity	289 min
		5th parity	301 min
		6th parity	312 min
		7th parity	306 min
		8th parity	349 min
		9th parity	342 min
Friend et al	1962	Older sows	Take longer to farrow

iv. Season and time of day

Little work seems to have been done relating these to duration of farrowing however Siecu, Paraipan, Penciu and Volinturi (1979) claimed December farrowings lasted 143 minutes on average while in September, this had been reduced to 87 minutes.

An effect according to time of day when farrowing occurred has been claimed by Friend et al (1962) with farrowings at night (6 p.m. - 6 a.m.) averag ing 306 minutes, daytime farrowings 276 minutes. A later study, however, (Fahmy and Friend, 1981) found no significant effect of season or time of day.

v. Gestation length

There is a significant ($P < 0.01$) increase in the duration of farrowing with increasing gestation length according to Fahmy and Friend (1981), and from a regression analysis of their results they calculated that each day's delay in farrowing leads to a 15 minute increase in the duration of farrowing.

3.8 Relationship between the duration of farrowing and stillbirth rate

Several authors have observed a positive relationship between duration of farrowing and stillbirth rate (e.g. Schafer, 1941;

Krehbiel, Miller, Flower, Swiger and Harvey, 1968; First and Bosc, 1979; Svendsen and Bille, 1980; Cavalcanti, 1980) and a selection of typical results is shown in table 3.10.

Table 3.10 Relationship between duration of farrowing and stillbirth rate

Author	Year	Duration of farrowing (min)	% stillbirth rate
Bille et al	1974a)	< 360	5.2
		> 360	12.5
Cavalcanti et al	1979	< 60	5.6
		61-120	5.0
		121-180	14.2
		181-240	15.7
		241-300	15.2
		301-360	8.6
		> 360	35.7
Friend et al	1962	1-60	0.0
		61-180	2.4
		181-300	5.5
		300-480	7.8
		> 480	10.5
MacDonald et al	1963	1-60	0.0
		61-180	0.0
		181-300	4.6
		300-480	5.0
		> 481	8.1
Timoshenko	1974	< 100	11.5) % stillbirth
		101-200	15.0) rate in
		> 200	18.9) litters with stillbirths
		Mean duration of farrowing (min)	No. stillborn pigs/litter
Randall	1968	195	0
		128	1
		262	2
		453	> 2

Thus it can be seen from the table that as farrowing time increases, stillbirth rate does likewise. In 1971, Wrathall reviewed the work of many authors over nearly 50 years and concluded that an increase in farrowing time leads to an increase in stillbirth rate but other authors have not been able to ascribe cause and effect although

Dzuik (1979) claimed that death is caused by a prolonged delivery (not vice versa) and quoted as evidence the fact that some apparently dead pigs can be revived.

In addition to the relationship between duration of farrowing and number of stillbirths, several workers have reported a prolonged birth interval preceding the delivery of a stillborn pig compared with a liveborn one, e.g. 45-55 minutes v. 13-18 minutes (Leman and Dzuik, 1975), 47 minutes v. 17 minutes (Janssen et al, 1973), 42 minutes v. 16 minutes (Schafer, 1941). Walters (1965), however, reported finding no evidence of a relationship between birth interval and incidence of stillbirths. Some workers have claimed that although the intervals preceding stillborn pigs are longer than those before liveborn pigs, it is not possible to correlate long intervals before the delivery of a piglet with the state of that piglet at birth. The mean interval before the birth of depressed piglets is shorter than that before normal piglets while in some protracted farrowings, there are no stillbirths (Pomeroy, 1960b; Randall, 1968). Randall concluded that prolongation of farrowing per se does not necessarily result in stillbirths although it may contribute to their aetiology. He proposed that in many cases a combination of factors resulted in a stillborn pig, whereas each factor separately would not have resulted in this.

3.9 Effect of duration of farrowing on subsequent piglet survival

Most authors seem to agree that an extended farrowing has an adverse effect on the survival of the piglet after birth. As long ago as 1952, Hellman and Prystowky recognised that a prolonged labour poses a serious threat to the neonate and the data of English (1969) indicated that piglets with a long delivery period were weaker than those with a shorter delivery period, as measured

by their longer times to cord breakage and first successful suckling. This weakness was not due to a lower birth weight and English proposed that it was a direct result of the longer delivery period but surprisingly, the apparent weakness at birth was not reflected in a higher mortality rate subsequently. Likewise England et al (1976) concluded from their data (shown in table 3.11) that there is no really marked effect on the postnatal survival of pigs from prolonged farrowings of up to 290 minutes as long as there are no specific difficulties during the farrowing.

Table 3.11 Relationship between birth interval and subsequent survival rates in piglets

	Length of time preceding delivery	
	Short	Long
Mean birth interval (min)	14	61
% survival to 35 days	83.1	78.9
Mean weight at 35 days	7854g	7718g

(from England et al, 1976)

It might be expected that piglet survival during a prolonged farrowing would be reduced compared to a more rapid parturition but as regards mortality due to trauma, Bille et al (1974a) reported a rate of 3.3% when the farrowing was under 6 hours, compared with 4.1% for longer farrowings, but these differences were not significant when the results were corrected for effect of litter size.

Finally, it appears as though a prolonged labour may have adverse effects on the subsequent behaviour of the dam towards her young. Herscher, Richmond and Moore (1963) reported that if a ewe has experienced a particularly difficult labour, she often shows little interest in her offspring and Duncan (1980) also claimed that a

long and stressful parturition may damage the formation of the mother - offspring bond which is so necessary for the survival of the young. In pigs, Gregory (1979) has also stated that prolonged farrowings not only cause an increased number of weak and stillborn piglets but that they also lead to more sows showing a reduced amount of maternal care (and frequently reduced lactation yields, too).

3.10 Dystocia

This has been defined as a condition which prolongs parturition or hinders the expulsion of the foetus (Zerobin and Sporri, 1972). There have been several classifications of dystocia (Zerobin and Sporri, 1972; Arthur, 1975) but it appears that uterine inertia is the most common cause in pigs (Jackson, 1972). The term inertia may include i) weak contractions, ii) unco-ordinated contractions and/or iii) cervical dystocia (Garrett, 1960). Primary uterine in ertia is when ineffectual contractions have occurred from the outset whereas secondary inertia involves cases where normal uterine activity has weakened and come to a standstill (Jackson, 1972).

Freak (1962) claimed he could identify behavioural traits in bitches that suffered from uterine inertia - "a quiet, stolid, lazy type which dislikes exercise and is unwilling to take any during pregnancy". In fact, there seems to be a relationship between exercise (or lack of it) and dystocia; it has, for example, been claimed that lack of exercise in pregnant sows results in weak labour (Stoss, 1944 cited by Ringarp, 1960; Sommer, 1979).

It has also been observed that uterine inertia is more frequent in those animals which lack exercise (Roberts, 1971) and in humans both Erdelyi (1962) and Muller-Tyl, Salzer and Mick (1976) found a beneficial effect of exercise on the duration of labour.

In commercial pig production it is commonly accepted that forcing a sow to walk around every one or two hours is a most successful way of treating a prolonged farrowing (Anon, 1980a).

The incidence of dystocia in pigs is much lower than in cattle and sheep, probably because of the small size of the foetus in relation to that of the dam. In their survey of over 100,000 culled sows, Dagorn and Aumaitre (1979) gave the reason of "farrowing difficulties" for 4% of these. Other estimates of porcine dystocia are even lower; 0.25-1% (Jackson, 1972), 0.25% (Jones, 1966b), 3% (Randall, 1972a).

Dystocia also seems to be more common in gilts than in sows; Jones (1966b) observed 2 cases out of 772 farrowings which were both gilts and Jackson (1972) also claimed that dystocia was commonest in younger animals. Zerobin and Sporri (1972) hypothesised that this was due to the resistance of the pelvic canal to the passage of the foetus, as the tissues have never been stretched before. These authors also speculated as to the role of too little foeto-cervical contact in dystocia and they quoted the work of Leibrecht (1953) who found sensory nerve endings in the anterior portion of the porcine cervix. They considered that stimulation of these nerve endings would be required in order to bring about the Ferguson reflex and the peak discharge of oxytocin.

With reference to the role of psychic factors, it has been stated (Condrau, 1969 cited by Zerobin and Sporri, 1972) that fear can cause muscle spasms which may lead to prolonged parturition and that the origin of pain and pain conductance in other animals is similar to humans (Walser, 1965 cited by Zerobin and Sporri, 1972).

These authors conclude, however, that it is not known whether birth pains are as intense in animals as they are in humans, or whether pain leads to dystocia or vice versa.

It has been noted (Jackson, 1972) that in 30% of cases in which dystocia is due to birth canal obstruction, the reason is due to distension of the urinary bladder. Jones (1966b) had previously observed that the completion of farrowing was accompanied by the passage of copious amounts of urine and Jackson speculated that, if labour was prolonged beyond the normal period, the bladder could become distended; however, his observations indicated that the bladder was not distended in all cases of prolonged labour.

Jackson also reported a breed difference in susceptibility to dystocia with Welsh and Large White sows being more susceptible than Landrace animals.

Chapter 4

STILLBIRTHS

4.1 Introduction

It has been claimed that stillbirths still account for 25% of all preweaning losses (Randall, 1972d) and this author divided stillbirths into 2 main categories i) epidemic outbreaks (which he considered were rare) and ii) the loss of 1 or 2 piglets in about one third of all the litters born. He claimed that most stillbirth losses occur from piglets dying during or immediately after birth and Dzuik (1979) confirmed this by reference to observations of researchers in the fields of hysterectomy and hysterotomy that nearly all the foetuses are alive in utero. Observations by veterinary surgeons on hysterectomy derived piglets have also been quoted as evidence that if a pig is not born mummified, it was definitely alive at day 112 of gestation. (Pond and Maner, 1974; Arthur, Noakes and Pearson, 1982). In the domestic species, more deaths occur at or near birth than during the subsequent stages of development and because these animals are not usually malformed, their loss represents a considerable economic wastage (Randall, 1978); in the region of 1 million pigs annually in the U.K. (Wilkinson, English, Lodge and Smith, 1982).

4.2 Characteristics of stillborn pigs

Stillbirths were classified by Sprecher, Leman and Carlisle (1975) into:

Type I Prepartum deaths (usually infectious)

Type II Intrapartum deaths (non-infectious).

This latter category includes piglets which are alive at birth but are suffering from hypercapnia and die soon afterwards.

Bjorklund (1981, loc. cit.) described the characteristics of stillborn piglets as follows:

Prepartum death

These show autolysis with a bluish discoloration of the skin and the frequent presence of excessive volumes of serosanguinous fluids in the subcutaneous tissues and body cavities.

Intrapartum death

These piglets show subcutaneous oedema and unexpanded lungs. (For piglets that die immediately after birth, the only difference is that the lungs are at least partly expanded).

Randall (1972c, 1972d) provided a fuller description of intrapartum stillborn piglets. Many of them had a slow heartbeat which gradually faded and ceased several minutes after delivery (range 0-13 minutes, mean 4.7 minutes). Measurements of blood pH, pCO_2 and plasma lactic acid levels showed that these piglets were in a severe state of respiratory and metabolic acidaemia which had the effect of depressing the respiratory centre in the brain so that they never breathed. Randall also found that stillborn pigs tended to be delivered more slowly than their liveborn littermates; the mean interval between births was 26 minutes for stillborn pigs and 13 minutes for liveborn. It has also been observed (Milosavlejic, Milijkovic, Sovljanski, Radovic, Trbojevic and Stankov, 1972) that in piglets which were apparently stillborn but could be revived, the birth interval from the previous piglet was slightly shorter

(23.7 minutes) than for piglets which could not be revived (29.0 minutes) but each of these birth intervals was much longer than the mean of 15.4 minutes for all piglets.

The incidence of congenital abnormalities in stillborn pigs is very low; the study by Randall (1968) showed that only 3.7% of stillborn pigs suffered from these i.e. most stillborn pigs are fully developed and quite normal although Herren (1980) reported that stillborn piglets had significantly lower brain weights.

With reference to the birth weight of stillborn pigs, most authors have reported that stillborn pigs are lighter than their liveborn littermates (table 4.1) while, in contrast to these results, McPhee & Zeller (1934) found a great variation in the weights of stillborn pigs but claimed that they were often heavier than liveborn littermates, and Bille, Nielson, Larsen and Svendsen (1974) reported that intrapartum stillbirths were usually normal sized or even above average sized pigs.

Table 4.1 Weights of stillborn pigs

Author	Year	Mean birth weights (g)	
		Stillborn	Liveborn
Carmichael & Rice	1920	985	1160
DeRoth & Downie	1976	947	1155
Pond et al	1960	less than liveborn	
Timoshenko	1974	960	1183
		Birthweight (g)	% stillbirth rate
Meyer et al	1976	<700	21.7
		700-999	10.3
		1000-1199	4.3
		1200-1799	1.2
		>1800	4.0
Sharp	1966	<800	14.3
		800-1199	7.1
		1200-1499	2.2
		>1500	1.1

With reference to the presentation of the piglet at birth and stillbirth rate, there appears to be a relationship between a posterior presentation and the likelihood of being stillborn. Randall (1968) reported that 41% of liveborn pigs are born posteriorly, but 44% of stillborn pigs which died prepartum and 61% of intrapartum stillbirths. Likewise, Sovljanski, Milosavljevic, Trbojevic and Radovic (1972) stated that 12% of posterior presentations are stillborn but only 3.6% of anterior presentations. Further evidence comes from the work of Milosavljevic et al (1972) who observed that in piglets which were apparently stillborn but could be revived, only 50% were posterior presentations whereas in those which could not be revived, 62% had been born posteriorly. There also appears to be a relationship between stillbirths and a broken umbilical cord at parturition; in his comprehensive study of the topic Randall (1968) reported that 22% of prepartum stillbirths had broken cords compared to 100% of intrapartum stillborn pigs. He also noted evidence of injury to the cord in 63.7% of intrapartum stillbirths. The number of piglets in which the umbilical cord had broken before delivery was significantly ($p < 0.05$) greater in those pigs born posteriorly (29.2%) than anteriorly (18.9%) (Randall, 1968) and it is possible that a posterior presentation predisposes to cord breakage and so to intrapartum stillbirth.

4.3 Estimates of stillbirth rate

A survey of the literature reveals remarkably consistent estimates of stillbirth rate over a period of 40 years (table 4.2) which is perhaps all the more surprising considering the wide variations in breed, geographical location, management systems etc.

Table 4.2 Estimates of stillbirth rate

Author	Year	SBR as % age total pigs born
Anon	1975	5-7
Asdell & Willman	1941	7
Backstrom	1973	5
Bauman et al	1966	6
Belic & Soldatovic	1965	4-6
Bignetti et al	1967	7
Bille et al	1974a)	6
Bjorklund	1981	5-7
Braude et al	1954	6
Brekke	1948	8
Cavalcanti	1979, 1980	4.8, 4-6
Day	1978	6
DeRoth & Downie	1976	6.5
Fahmy & Bernard	1971	7
Gracey	1955	5
Hutchinson et al	1954	5
Ilancvic & Salahovic	1973	5
Ilancvic et al	1968	7
Kernkamp	1965	6
Lynch	1965	6
Maksimovic	1976	5
McPhee & Zeller	1934	5
Milosavljevic et al	1972	6
Milosavljevic et al	1973	9
Ministry of Agriculture	1959	6
Ministry of Agriculutre	1960	6
Randall	1968	6
Randall & Penny	1967, 1970	6
Sharpe	1966	4
Simensen & Karlberg	1980	7.8
Sovljanski & Milosavljevic	1965	11
Sovljanski et al	1971	9
Sprecher et al	1974	5-7
Sreckovic et al	1972	4-7
Stanton & Carroll	1974	5-7
Steinbach	1971	6

4.4 Factors influencing stillbirth rate

i. Effect of sow age on stillbirth rate

Many authors have noted an increase in stillbirth rate with increasing sow age (table 4.3) although Perry (1956) claimed the two were not related.

Table 4.3 Effect of sow age on stillbirth rate

Author	Year	Parity	% stillbirth rate 1	2	3	4	5	6	7	8	9	10
Backstrom	1973		5	5	5	5	5	7	9	7	9	8
Barr	1980b)		3-4								20	- 25
Bille et al	1974a)		4	5	5	6	8	8	7	12	11	14
Kernkamp	1965		5					19				
Lynch	1965		5	3	6	10	8	11	10			
Majerciak	1964			5			11					
Meat & Livestock Commission	1980		5		7			10				10
Milosavljevic et al	1973		8								19	
Pour & Hovorka	1978		4	3	4	5	5	6	6	7	5	6
Schafer	1941		2					12				
Stepulenkova & Sukhorukov	1977		6	8	10	15	20	16				
Timoshenko	1974		2	2			7	7	16	16	16	
			No. stillborn pigs/litter									
Rasbech	1969		.5	.5	.6	.8	.9	1.2	1.1	1.1	1.2	1.7
Simensen & Karlberg	1980		.7	.7	1.0	.8	1.4	1.4	1.4			

In addition to the age of the sow, there are conflicting reports as to the influence of age at first farrowing on stillbirth rate. Some workers have found a significant difference between gilts mated at 7-8 months (0.5 stillborn pigs/litter) and those mated at 11-16 months (1.1 stillborn pigs/litter) (Mitic, Sljivovacki, Kostic, Gajic, Radovanovic 1967) but others have reported no effect (Arganosa and Rodillo, 1972). With reference to the reasons for an increase in stillbirth rate with advancing age, Pickering (1980) suggested that the lower rate in gilts was due to better muscle tone although Dunne and Hokanson (1963) claimed that the smaller pelvis in a gilt could cause more stillbirths. Dunne (1975) stated that the major cause of stillbirths in gilts was the presence of infectious agents whereas sows tend to have developed immunity against these and stillbirths are the result of a long farrowing or the position of the foetus in the uterus.

ii. Effect of litter size on stillbirth rate

The general consensus of opinion in the literature is that stillbirth tends to be highest in very large and very small litters (table 4.4).

Other authors in agreement with this general trend are BeVier and Dzuik, (1976); McPhee and Zeller, (1934); Perry, (1956); Randall, (1968); Randall and Penny, (1970); Sovljanski and Milosavljevic, (1965).

Table 4.4 Effect of litter size on stillbirth rate

Author	Year	Litter size	% stillbirth rate
Backstrom	1973	1-4	8
		5-6	6
		7-8	5
		9-10	4
		11-12	5
		13-14	5
		15-16	9
		17-18	11
		> 18	16
Ministry of Agriculture	1959	8	6.0
		9-10	4.1
		11-12	4.8
		13-14	5.8
		> 14	9.6
Sharpe	1966	4-8	6.6
		9-11	3.4
		12-14	2.3
		15-17	8.9
Sovljanski et al	1971	< 5	11.0
		16	12.2
		17	15.5
		18	12.5
		> 19	22.6
Sovljanski et al	1973	5	3.1
		> 19	22.6
			No. stillborn pigs/litter
Simensen & Karlberg	1980	≤ 8	0.3
		9-10	0.6
		11-12	0.7
		13-14	1.1
		> 15	1.9

In order to try to explain the cause of an elevated stillbirth rate in small litters, BeVier and Dzuik (1976) operated on gilts at day 40 of gestation and reduced the number of living foetuses to 2 per animal, either both at the cervical end or both at the oviducal end. Their results showed that 25% of the cervical foetuses were born dead but 94% of the oviducal foetuses. They claimed

that this indicated that in small litters, an isolated piglet located near the cervix is likely to be born alive, whereas one located at the oviducal end will not be. These latter piglets may have to travel a distance of 2 metres before presentation and since the umbilical cord is only 0.5m long, it is likely that the cord will break and the piglet will become asphyxiated. Dzuik (1979) claimed that in a small litter, an anteriorly located foetus would have to pass through a previously unoccupied and consequently undilated section of uterine horn. BeVier and Dzuik claimed that this phenomenom could have a commercial significance in cases such as SMEDI where several foetuses may be reabsorbed and only isolated ones left.

In order to try to explain the increased stillbirth rate in large litters, Wrathall (1971) speculated that it was probably a reflection of the increasing proportion of very small piglets. He proposed that such piglets would be likely to have weak umbilical cords which would be more susceptible to early rupture. He also thought that a large litter size could increase the number of stillbirths by prolonging farrowing; Schafer (1941) and Ministry of Agriculture, Fisheries and Food (1959) thought likewise while Bille et al (1947a) considered that uterine atony was important in such cases. Among the workers who also found an increase in stillbirth rate with increasing litter size are Pond, Roberts, Dunn and Willman (1960); Belic and Soldatovic (1965); Glastonbury (1976); Svendsen and Bille (1980).

iii. Effect of sire on stillbirth rate

Minkema (1967) found that there was no significant sire effect in gilts, but that there was a highly significant effect in sows, while Schofield and Penny (1969) observed that the stillbirth rate for Landrace sired litters (6.9%) was significantly lower than that for Large White sired litters (11.4%) within the same herd.

iv. Effect of breed on stillbirth rates

Various authors have reported differences in the number of stillborn pigs produced between different breeds (table 4.5). However, as Sovljanski et al (1977) pointed out, these results may also reflect differences in general management and feeding of the animals, in addition to the genetic crosses employed. They concluded that, generally, the effect of breed on stillbirth rate is not marked, a sentiment with which McPhee and Zeller (1934), Asdell and Willman (1941) and Backstrom (1973) agreed.

Table 4.5 Effect of breed on stillbirth rate

Author	Year	Breed	% stillbirth rate
Belic & Soldatovic	1965	Landrace	5.6
		Large White	4.1
Cavalcanti	1979	Duroc	4.8
		Hampshire	6.0
		Landrace	4.7
		Yorkshire	3.9
Cody	1966	Large White	4.3
		Landrace	4.9
Pond et al	1960	Berkshire	6.3
		Chester White	3.3
		Yorkshire	8.2
Sovljanski et al	1977	Large White	6.5
		Swedish Landrace	4.8
		Crossbred	4.7
Sreckovic & Nikolic	1975	Large White	7.6
		Swedish Landrace	6.4
		Dutch Landrace	5.4
		Pietrain	14.1

v. Effect of sex on stillbirth rate

McPhee and Zeller (1934) found no effect of sex on stillbirth rate while Asdell and Willman (1941) and English (1969) found no significant differences between sex of stillborn pigs. In contrast, MacDonald, Holness and Moxley (1963) found that 64% of all stillbirths were male, while Ilancvic, Nikolic and Pavlovic (1968) obtained results showing 0.43 male stillborn pigs/litter versus 0.38 females and Herren (1980) also found that males constituted 54% of piglets which were either stillborn or died neonatally.

vi. Effect of gestation length on stillbirth rate

Perry (1956) found no correlation between gestation length and the number of stillborn pigs while Cavalcanti (1980) found no significant difference between long and short gestation lengths. Other authors, however, claimed to have observed a definite relationship (table 4.6).

Thus, there is a general consensus of opinion that gestation lengths which are both longer and shorter than normal are associated with an increased stillbirth rate.

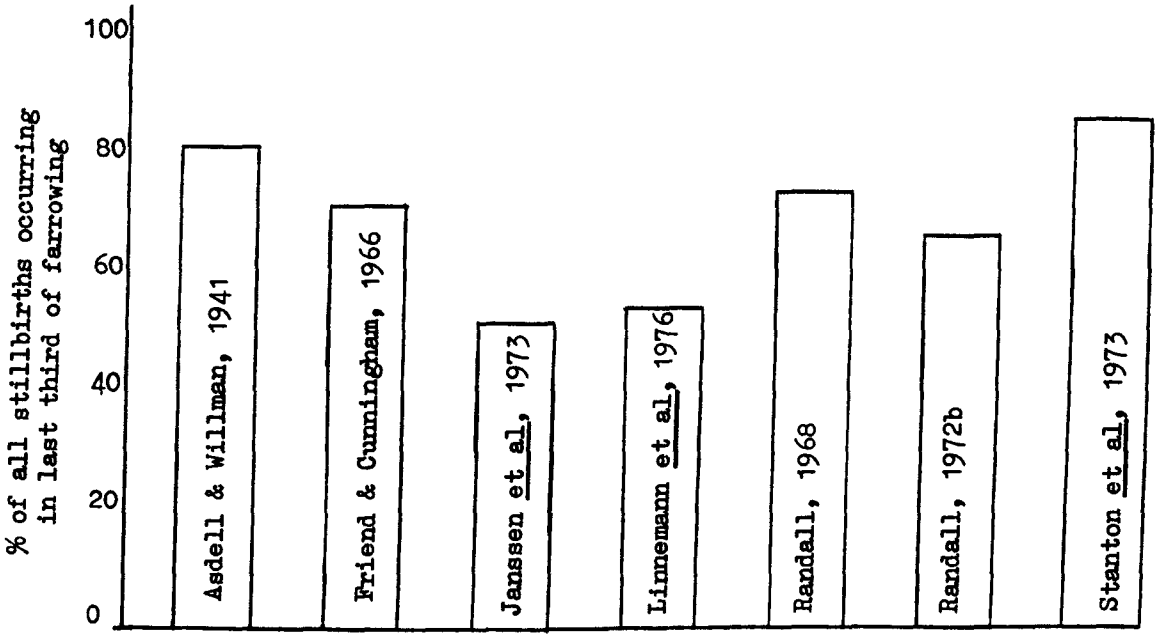
Table 4.6 Effect of gestation length on stillbirth rate

Author	Year	Gestation length (days)	% SBR
Aumaitre et al	1979	<112	Sig. increase
Bus'ko	1975	long & short	Increase
Friend et al	1962	≤113	3.9
		114-116	5.5
		≥117	10.4
Lynch	1965	Long	Increase
Martin et al	1977	Long	Increase
Minar & Schilling	1970	Long	Increase
Randall & Penny	1970	<110	Increase
Schafer	1941	Long	Increase
Tomov et al	1974	<113	Increase

vii. Effect of birth order on stillbirth rate

It is apparent from the literature that there is a positive relationship between stillbirth rate and birth order i.e. more pigs are born dead in the later stages of farrowing (fig. 4.1). Other authors to agree with this general tendency are BeVier and Dzuik, 1976; Pavlovic, Sovljanski and Radovic, 1977; Svendsen and Bille, 1980. The reasons for this are discussed later, but are related to asphyxia following the rupture of the umbilical cord.

Fig. 4.1 Occurrence of stillbirths in last third of farrowing process



viii. Effect of season on stillbirth rate

Several authors have investigated the effects of season on stillbirth but without specifying whether the seasonal effect was due to temperature, humidity or day length. Both Randall (1968) and Randall & Penny (1970) observed a high "stillbirth" rate (approximately 10%) during cold winter months on farms where

environmental control in farrowing houses was minimal; in controlled environment houses, however, the rate was only 4%. The authors considered that this probably reflected an increase in losses due to farrowing and this may also be the case with some of the other results shown above. Backstrom (1973), however, could find no conclusive evidence for the effect of temperature on stillbirths, although Steinbach (1971) working in Nigeria found a significant increase in stillbirth rate during the hottest and most humid months. Heat stress alone has been shown to cause more stillbirths (Omtvedt, Nelson, Edwards, Stephens and Turman, 1971; Day, 1978). A few authors (Braude, Clarke and Mitchell, 1954; Ilancvic, Nikolic and Pavlovic, 1968; Kernkamp, 1965) found no relationship between season and stillbirth rate but the results of other investigations are shown in table 4.7 which indicates that there is a tendency for more stillbirths in the winter and spring months.

Table 4.7 Effect of season on stillbirth rate

Author	Year	% stillbirth rate			
		Spring	Summer	Autumn	Winter
Asdell & Willman	1941	9.2		4.9	
Backstrom	1973		Lowest		
Bauman et al	1966			Highest	
BeVier & Backstrom	1980				Highest
Bignetti et al	1967		8.8		6.9
Bille et al	1974a)	5.1	6.2	7.4	6.6
Krutyporokh & Klochun	1973				Highest
Ministry of Agriculture	1959	Highest			
Schofield & Penny	1969		7.9		10.8
Timoshenko	1974	7.4		3.4	

ix. Effect of light on stillbirth rate

There has been little work done in this area but Klotchov, Klotchkova, Kim and Belyaev (1971) investigated the effect of additional illumination on the reproductive performance of gilts and found that extra light caused an increase in litter size at birth and a reduction in stillbirth rate (table 4.8).

Table 4.8 Effect of additional illumination on stillbirth rate

Breed	North Siberian x Lacombe		North Siberian x Landrace	
Treatment	Control	17 hrs light	Control	24 hrs light
% SBR	3.1	1.9	2.0	0.9
Litter size	9.7	10.5	10.2	11.0

(from Klotchov et al, 1971)

x. Effect of bacterial infection on stillbirth rate

Specific bacterial infections such as leptospirosis are known to cause stillbirths (Bjorklund, 1981) although Bille, Nielsen, Larsen and Svendsen (1974) were unable to relate the results of bacteriological examinations of sows and stillborn piglets. It is likely that infectious diseases play only a very limited role in the aetiology of death at or around the time of parturition, instead death generally results from the failure of the newborn to adapt to its new environment (Randall, 1978).

xi. Effect of exercise on stillbirth rate

It is difficult to quantify the amount of exercise undertaken by pregnant sows but it is reasonable to assume that those animals which are tethered or stalled will have less opportunity for exercise than loose housed sows. Swedish workers have reported on several occasions

that strictly confining sows during gestation leads to an increase in the intrapartum stillbirth rate (Bille et al, 1974a; Bille, Svendsen, Nielsen and Riising, 1976; Svendsen and Bille, 1980); some typical results are shown in table 4.9.

Table 4.9 Effect of restricted exercise on stillbirth rate

Type of housing	% prepartum SBR	% intrapartum SBR
Tethered or confined	1.74	5.17
Loose housed	1.28 ($P<0.01$)	3.27

(from Bille et al, 1974a)

	% total SBR
Tethered	5.4
Loose housed	3.4 ($P<0.05$)

(from Svendsen, Andreasson & Bengtsson, 1981)

In contrast, other workers (e.g. Blendl, 1974) have recorded a higher stillbirth rate in group housed sows compared to those confined in individual accommodation (5.0% v. 0.3%). Likewise, Majerciak (1964) found a higher (18.6%) stillbirth rate in sows which had been reared at pasture compared to those kept under confined conditions (11.1%) but both of these rates are considerably higher than normal estimates. Gravas (1981) also reported a higher stillbirth rate in free moving sows kept in stalls rather than tethered sows (0.7 pigs/litter v. 0.1 pigs/litter) but as the stall size was the same for each group (i.e. 2.0 x 0.7m), the amount of exercise available for the untethered sows was severely restricted. In contrast to these results, a Danish study has shown no difference in stillbirth rate between tethered and loose housed gilts

(Landsudvalget, 1982).

Hale, Booram and McCormick (1981) compared stillbirth rate in sows and gilts which had been forcibly exercised (i.e. made to walk approximately 0.48 km) for 15 minutes daily, 5 days a week throughout a 100 day period of gestation, with other animals that had remained tethered; they found the exercised animals produced 0.55 stillborn pigs/litter, whereas the non-exercised group produced 0.74.

xii. Effect of drugs and hormones on stillbirth rate

With reference to drugs, various workers have observed that feeding dichlorvos to pregnant sows and gilts results in a decreased stillbirth rate (Batte, Robinson and Moncol, 1969; Leman and Sprecher, 1976; Siers, Schooley, Brown and Stanton, 1977; Bjorklund, 1981). The administration of parasympathomimetic drugs such as neostigmine and carbacholine also results in a decreased stillbirth rate (Sprecher, Leman and Carlisle, 1975; Cropper, Leman and Diehl, 1975; Leman and Sprecher, 1976; Wilkinson et al, 1982). Neostigmine is an anticholinesterase material and so causes prolonged smooth muscle contraction, while carbacholine mimics the action of acetylcholine in producing muscle contraction (Sprecher et al, 1975).

The hormonal control of parturition is a very complex process, so it is perhaps not surprising that the administration of various hormones can drastically affect the farrowing process. Administration of progesterone causes an increase in the number of stillborn piglets (Minar and Schilling, 1970; Nellor, Daniels, Hoefer, Wildt and Dukelow, 1975; Coggins, Van Horn and First, 1977; Sherwood, Wilson, Edgerton and Chang 1978). By contrast, the infusion of

prostaglandin $F_{2\alpha}$ when parturition was prevented, increased stillbirth rate (Coggins et al, 1977) but reduced it when the sows were allowed to farrow naturally (Humke, Seidel and Scherp, 1979).

Conflicting results were also obtained concerning the administration of pituitrin by Asdell and Willman (1941); in one trial the hormone reduced the stillbirth rate but in a second trial it did not and the authors were unable to offer any explanation for these results.

Finally, injection of ACTH on day 110 has led to reduced stillbirth rates in both Danish Landrace and Pietrain sows, probably as a result of reducing farrowing time (Ludvigsen, 1982).

xiii. The effect of psychological stress during pregnancy on stillbirth rate

It has been demonstrated that the adrenal medulla is implicated in the stillbirth response of mice which have been subjected to chronic psychological stress during pregnancy (Caldwell, 1962). The mice had been placed in a situation (the application of an electric current) which created strong anxiety and they were then trained to reduce this anxiety by making an appropriate response. When the animals were pregnant, they were exposed to the anxiety-arousing situation but they were prevented from making their learned response to reduce their anxiety. Certain of the animals underwent surgical demedullation of the adrenal glands while others were sham operated and a third group left as a control.

The percentage stillbirth rate for the 6 experimental conditions is shown in table 4.10.

Table 4.10 Effect of psychological stress applied during pregnancy on stillbirth rate in mice

	Non-operated controls	Sham operated	Demedullated
Stressed	18.5	15.1	5.6
Non-stressed	1.0	3.2	0.0

(from Caldwell, 1962)

The stressed animals in the non-operated and sham operated groups had a significantly higher incidence of stillbirths. Thus the results show that exposure to psychological stress during pregnancy can cause the death of foetuses and that this is somehow mediated via the adrenal medulla i.e. it involves the production of adrenalin. Caldwell speculated as to whether the stress response involved a vasoconstrictive effect in the uterus.

xiv. Effect of various nutritional factors on stillbirth rate

a) Feed level

Salmon-Legagneur and Jacquot (1961) found that sows on an ad libitum diet from service to farrowing produced a mean of 0.6 more stillborn pigs/litter than other sows with a 50% feed restriction while Omtvedt (1967) also claimed that a high plane of nutrition (0.4 more stillborn pigs/litter in sows and 0.2 more stillborn pigs in gilts). According to Zintzen (1974), overweight sows tend to suffer from complications at birth such as weak uterine contractions and a narrow, inelastic vagina, so that piglets are more likely to be stillborn.

b) Toxic substances

Miller, Hacking and Gross (1973) described cases of increased stillbirth rate in sows as a result of ingesting Fusarium toxin and Bjorklund (1981) also claimed that the consumption of mouldy grain by sows can cause more stillbirths. High atmospheric carbon

monoxide levels caused by a faulty gas burner were responsible for an increase in stillbirths from 7% to 53% in one incident (Wood, 1978).

c) Specific nutrients

1. Iron (haemoglobin level)

A low haemoglobin level has been implicated as a causative factor for increased stillbirth rate on several occasions e.g. Archibald and Hancock, (1939); Dunne and Hokanson (1963); Leman and Dzuik (1975); Tansinne, Gurtler and Brenner (1977). The critical level seems to be around $10g/100cm^3$; below this the stillbirth rate rises steeply (Leman and Dzuik, 1975; Tansinne et al, 1977). It has been suggested that the low haemoglobin levels in foetuses of anaemic sows may have diminished their ability to survive the hypoxic stresses of birth, leading to stillbirth (Moore, Redmond and Livingstone, 1965) but English (1976) having noted that a high incidence of stillbirths is associated with a low haemoglobin level in the sow's blood, claimed that this was unlikely to be a major factor in herds where the incidence of stillbirths is around the 5% level. In complete contrast to the above results, Petersen, Lave and Nielsen (1979) found no significant correlation between the sow's blood haemoglobin level and the number of stillborn pigs.

2. Vitamin A

It is clearly documented in the literature that a deficiency of vitamin A can lead to an increased stillbirth rate e.g. Hughes (1934); Pullar (1950); Goodwin and Jennings (1958); Saunders (1958). In no case, however, is the critical amount

of vitamin A quantified and many of the diets fed were grossly deficient (e.g. the barley and salt diet which, was fed to sows from a weight of 20kg in Hughes (1934) experiment and which produced no discernible amount of vitamin A in the liver).

3. Calcium

Both Davidson (1930) and Dunne and Hokanson (1963) have reported that feeding a pregnant sow a diet deficient in calcium can cause more stillborn pigs. In Davidson's experiment, sows were fed a ration consisting of 94 parts of barley meal, 94 parts of maize meal, 8 parts of bean meal, 14 parts of bloodmeal and 1 part salt, in addition they received cod liver oil and orange pulp to provide vitamins A, D and C. The stillbirth rate in this experiment increased over succeeding generations, as the sows continued to be fed on the ration, from 4.8% to 50% in the 4th parity. More recent experiments (McCrea, Handlin, Johnston and Eargle, 1979) have shown that when diets containing 0.76% calcium and 0.59% phosphorus were fed to pregnant sows, there was a significantly higher stillbirth rate compared to sows receiving rations of 1.09% calcium and 0.85% phosphorus.

4. Vitamin C

Brown, Harris and Cummings (1972) observed a sharp decline in the ascorbate content of the foetal adrenal glands at birth and they proposed that the accompanying hypoxic stresses entail the utilisation of large amounts of ascorbate in order to produce and release adrenal hormones, as experimental hypoxia of the dam produced similar results. Likewise, Kitabchi (1967)

and Kitabchi and Duckworth (1970) have shown that ascorbate is involved in the release of the adrenal hormones. In consideration of this, Wrathall (1975) speculated that a possible implication could be that a deficiency of vitamin C may have an adverse effect on the ability of piglets to survive normal parturition and it could lead to an increased stillbirth and neonatal mortality rate.

In conclusion, it is apparent from the literature that deficiencies of specific nutrients can lead to an increase in the number of stillborn pigs but, although details of actual nutrient levels are often lacking, it seems as though most of the experiments have involved the feeding of grossly deficient rations and it is reasonable to assume that modern commercial sow rations will contain sufficient of these nutrients to prevent any adverse effects on stillbirth rate.

Chapter 5

ASPHYXIA

5.1 Introduction

The term asphyxia has been defined as involving a simultaneous decrease in the intake of oxygen (ranging from slight hypoxia to complete anoxia) and elimination of carbon dioxide i.e. hypercapnia (James, Weisbrot, Prince, Holaday and Apgar, 1958).

Asphyxia may occur at any stage of the life history but within the context of this thesis, it is neonatal asphyxia which is the most important as severe cases will result in a stillborn animal, whereas less severely asphyxiated neonates may still suffer from depressed viability at birth and consequently a reduced performance. Factors which may contribute to intra-uterine asphyxia have been defined by James and Burnard (1961):

1. Compression of the umbilical cord.
2. Changes in uterine blood flow.
3. Partial separation of the placenta.
4. A reduction in maternal gas exchange e.g. straining and breath holding.

In addition to these, Randall (1978) added the following:

1. Damage to the umbilical cord from knotting or premature rupture.
2. A reduction in the oxygen carrying capacity of either maternal or foetal blood.
3. Any impairment to the maternal circulation.

These factors will be considered in more depth later.

5.2 Behaviour of the asphyxiated neonate

The pattern of behaviour in asphyxiated neonates is remarkably similar, irrespective of species (Randall, 1978, 1979). Initially there is a period of struggling and rapid gasping during which blood pressure rises and bradycardia becomes profound. A relatively short period of primary apnoea follows, after which there is a period of more regular and deeper gasping which becomes more frequent terminally. This is then followed by a period of secondary apnoea while heart rate and blood pressure fall. If the neonate is in the primary stage of apnoea, resuscitation will restore blood oxygenation and heart rate so that the animal will recover. If, however, the apnoea is at the secondary stage, the respiratory centre is already damaged to such an extent that outside stimuli will not induce gasping. (From a commercial viewpoint, attempts at resuscitation are always worthwhile since the producer will probably not know at what stage of apnoea the neonate is in).

5.3 Initiation of respiration

By its very nature, breathing is so much a part of everyday life that one could easily regard the initiation of breathing in the newborn animal as a straightforward process, but this is too simplistic an approach. One of the early workers in this field (Barcroft, 1946) proposed that at birth there would be a flood of stimuli from the skin, in addition to those from the muscles and joints, due to a lowering of the ambient temperature and to the fact that the foetus is no longer supported by a fluid; twenty four years later, Stave (1970) agreed and also considered that there would be intense stimulation of the peripheral chemoreceptors.

Burns (1963) suggested that breathing would be initiated when there was a sufficiently high input of potentials from various sensory neurons to activate the efferent respiratory arcs and these sensory neurons could include temperature, tactile, pain, visual, auditory and proprioceptive receptors (Stave, 1970). Once respiration has been initiated, the maintenance of breathing at an arterial pO_2 which is substantially above that achieved in foetal life, can be attributed to a continued inflow of sensory stimuli to the respiratory centre (World Health Organisation, 1965).

With reference to the initiation of respiration in piglets, Jones (1966b) reported that immediately after expulsion the piglets were apnoeic for a short while, before respiratory efforts began. Randall (1972a) agreed, describing how, immediately following delivery, the apnoea usually lasts for up to 15 seconds before the initial respiratory movements occur; these consist of 5-6 gasps and coughing to clear the upper respiratory tract and are followed by rapid shallow panting which lasts up to 20 seconds before the regular rhythm is established. In another study (Randall, 1971) he claimed that the first few of the irregular gasps after delivery are not true respiratory breaths in terms of gas exchange, and some piglets inhaled amniotic fluid with their first breath and coughed for some time following this (Randall, 1968).

5.4 Length of survival after asphyxiation

Generally, neonatal animals are far more resistant to asphyxiation than are adults (Kabat, 1940) while Fazekas, Alexander and Himwich (1941) showed that the survival time after asphyxiation depended on the degree of physiological maturity of the animal

(i.e. the more mature having shorter survival times), which they claimed was probably linked with the cerebral metabolic rate as this is lower in more immature animals. Thus in Rhesus monkeys, Dawes, Jacobsen, Mott and Shelley (1960) observed a survival time of more than 20 minutes at a gestational age of 120 days, but this had decreased to less than 10 minutes at term. In lambs, Dawes, Mott and Shelley (1959) found that 85 day foetuses had survival times of 40–60 minutes after the umbilical cord had been tied, whereas older foetuses of 126–146 days were only able to maintain blood pressure and heart rate for 10–15 minutes and adult ewes only survived for up to 7 minutes. In pigs, Randall (1979) investigated the survival time after inflicting anoxia on foetuses of 2 gestational ages (table 5.1). Randall considered that these results were in agreement with the general hypothesis outlined above i.e. the short survival times showing that the pig is a relatively mature species at birth. He found, however, that there was a considerable variation between individuals, so that some foetuses within a litter are more susceptible than others. He proposed that stretching of the umbilical cord during farrowing would tend to decrease the umbilical circulation and so in such cases, survival times following cord rupture would be very short. He also noted that the strength of the umbilical cord seems to vary between litters, which again could influence cord rupture and thus survival after asphyxiation.

Table 5.1 Survival of pig foetuses after asphyxiation

Age of foetus (days)	Time to last gasp (min.)	Time to last heart beat (min.)
97	5.4	30.4
110–112	5.1	22.4

(Randall, 1979)

The ability to survive asphyxia is directly related to cardiac glycogen level, as the ability of the heart to keep beating depends on anaerobic glycolysis of cardiac glycogen (Dawes, 1968; Dawes et al, 1959). In view of this, it is perhaps surprising that injections of insulin should have reduced survival times in rats after asphyxiation, although if survival depends upon mobilisation of cardiac glycogen, insulin would have inhibited this. Randall (1979) certainly observed hyperglycaemia in his asphyxiated pig foetuses but tissue analysis showed that it was only cardiac and liver glycogen which had been mobilised, muscle glycogen was unaffected.

As the brain has virtually no glycogen reserve (Shelley, 1961) the respiratory centre depends on the anaerobic respiration of glucose brought to it by the bloodstream. Anoxia leads to the release of catecholamines from the adrenal medulla (Comline and Silver, 1958) which may help to mobilise the glycogen stores. In reality, the foetus may be subjected to repeated episodes of anoxia while in utero and these may have a cumulative effect in depleting cardiac glycogen and hence the ability of the foetus to withstand the stresses of delivery (Stafford and Weatherall, 1960) although according to Stave (1970), the neonate is remarkable in its tolerance to even potent stressors such as hypoxia and anoxia.

Since asphyxiation is associated with the condition of acidosis (see later), it is not surprising that several workers have found that treatment of the asphyxiated foetuses with an alkali as well as glucose, prolongs their survival time (Adamsons, Behrman, Dawes, Dawkins, James and Ross, 1963; Dawes, Jacobson, Mott, Shelley and Stafford, 1963; Dawes, Mott, Shelley and Stafford, 1963).

5.5 Meconium staining

The mammalian foetus eliminates urine through its urachus into its amniotic bladder and this becomes diluted in the amniotic fluid in which the foetus is suspended (Fraser, 1974). The foetus undertakes swallowing reflexes from an early age so that some amniotic fluid is swallowed but the amount swallowed increases towards term, when the quantities of fluid consumed may greatly exceed its own body weight. As a consequence of this, the alimentary canal of the foetus accumulates solid residues (e.g. bile pigments, desquamated cells, foetal hair, mucopolysaccharides etc.; Morison, 1970; Fujikura and Klionsky, 1975) and this continues until the rectum also becomes filled. Fraser claimed, however, that it is unusual for the foetus to defaecate unless it is stressed during the birth process, in which case the foetal faeces (meconium) passes into the amniotic fluid and the foetus itself becomes stained with meconium (orange/brown colouring).

With the origin of meconium staining outlined above, it is easy to see how the degree of staining may indicate the extent of the anoxic or hypoxic stress undergone. Dawkins (1966) described how a period of anoxia or hypoxia causes contraction of the colon so that meconium is discharged into the amniotic cavity. In addition, he claimed that anoxia stimulates foetal gasping and so the meconium-containing amniotic fluid is sucked into the lungs and being a very viscous material, it is hard for the foetus to remove it. Meconium may be sucked into the very small air passages so that they are blocked, or it may act as a valve in that air can pass the obstruction during inspiration but cannot pass back during expiration.

This in turn may cause local over distension of the lung beyond the plug and initiate a rupture into the loose perivascular lymphatic tissue which in severe cases may lead to mediastinal emphysema and embarrassment of the venous return to the heart, or it may cause rupture of the pleural cavity and pneumothorax (Dawkins, 1966).

While they did not give details of such severe consequences, Randall and Penny (1967) did observe the presence of meconium in the trachea and/or bronchi of 53 out of 67 intrapartum stillborn piglets. They found that the consistency of the meconium varied considerably; in most cases, the trachea was filled with a mixture of very soft meconium and amniotic fluid, while the bronchi also contained similar material plus some small pellets. In other pigs, however, firm pellets were found throughout the respiratory tract with larger pellets often being present at the bifurcation of the trachea which, they postulated could act as a physical block to the passage of meconium. In contrast to the general view that the tenacious mixture of meconium plus amniotic fluid would hinder respiration, Fujikura and Klionsky (1975) considered that the bile pigments in meconium have a strong surface active action, and they proposed that aspirated meconium could reduce surface tension in pulmonary alveoli and thus facilitate alveolar expansion at birth but they provided no experimental evidence to confirm this hypothesis.

Referring back to the possible relationship between the intensity of meconium staining and the degree of hypoxia encountered, although it is generally accepted that the presence of meconium on the body is an indication of hypoxic stress (Browne and McClure-Browne, 1964;

Fujikura and Klionsky, 1975; Potter, 1961; Walker, 1954; Wrathall, 1971) the relationship is not a straightforward one. Randall and Penny (1967) found the degree of skin staining to be very variable between pigs and although Randall (1968) found evidence of staining in 79% of all prepartum stillbirths and 84% of all intrapartum deaths, he also noted staining in 76% of all liveborn pigs! Randall suggested that the differences in degrees of staining could be due to variations in the consistency of the meconium, which in turn may reflect the length of time the meconium has been in contact with the amniotic fluid. In normal, viable piglets with no meconium staining, the rectum contained firm, dark green pellets which he proposed was the normal consistency of the material. He claimed that once passed into the amniotic fluid, the pellets would soften and break up, so that an orange-brown staining over the body surface indicates an earlier period of hypoxia. In his study, Randall found that all the prepartum stillborn piglets had loose meconium on the skin surface and as meconium was also present between the skin and the amnion in all cases, he considered that such staining was unlikely to have occurred as a result of contact between the piglet and any meconium lying loose in the vagina or uterus.

In their 1967 study, Randall and Penny also found a great variation in the degree of skin staining which was not related to the amount of meconium found elsewhere. They suggested that this could be due in part to the consistency of the meconium passed; well formed pellets may not stain the skin so intensely but instead may be inhaled.

In the conclusion to his work on stillbirths, Randall (1968) claimed that there was no definite relationship between the intensity of meconium staining and the viability of the piglet at birth. Although this may seem surprising at first glance, he explained the apparent anomaly by suggesting that it was possible that piglets which had been subjected to hypoxia some days before parturition, might recover, but the pellets of meconium voided at that time would soften in the amniotic fluid and stain the piglet heavily. With reference to viability, however, he observed a lower incidence of loose meconium staining in the smaller litters and suggested that the placental reserve in such litters could be higher than in larger litters.

Studies on other species have also emphasised the indirect relationship between meconium staining and viability at birth. Abramovici, Brandes, Fuchs and Timor-Tritsch (1974) concluded from their study of human infants that newborn hypoxic infants did not pass meconium in greater amounts (or more frequently) than normally oxygenated babies. However, Saling (1968) stated that during hypoxia, the vital foetal organs receive a near normal blood supply while non-vital organs (such as the skin and gut) undergo vasoconstriction which in the case of the gut, causes the release of meconium. Abramovici et al suggested that a foetus which passes meconium may not necessarily be severely asphyxiated, instead it may be in a state of temporary compensated foetal distress, whereby the vital organs are well oxygenated but the non-vital organs are suffering from hypoxia.

Finally, it has been suggested that meconium staining could indicate that the foetus had attained a very advanced stage of maturation at the time of birth (Fraser, 1974). This author proposed that there is a limit to the length of time that a foetus can retain meconium in its rectum and if its body maturation progresses beyond a certain point, defaecation could occur before birth. He quoted the lamb as being the most mature of the farm species at birth (on the basis of its coat length) and as it is frequently stained, he cautioned that it is unwise to assume that such staining always represents a prepartal or intrapartal hypoxic stress. The overwhelming weight of the evidence does not entirely support his hypothesis however.

5.6 Effects of acute hypoxia

i. Anatomical changes

As long ago as 1928, Landis suggested that a period of acute hypoxia or anoxia gives rise to increased permeability of the capillary walls which Randall (1968) proposed would account for the oedema which he observed in all cases of intra-partum stillbirths. Randall noted that there were fibrin strands present in the peritoneal cavity and together with the high protein content in the pleural and pericardial cavities, he deduced that this was the result of a marked increase in capillary permeability and loss of protein to the extra-vascular spaces would upset the osmotic balance and increase the flow of fluid into the extra-vascular tissues. Potter (1961) also agreed with this general hypothesis, claiming that if foetal anoxia was gradual, the capillary walls became more permeable so that fluid escaped causing oedema.

Acute hypoxia also affects the central nervous system according to Windle and Becker (1943). These workers asphyxiated guinea pigs in utero and on resuscitation, they examined the central nervous system of both control and experimental animals, when they found that 65% of the asphyxiated animals showed evidence of histopathological changes whereas none of the control animals did.

ii. Changes in post-natal behaviour

In addition to the histological examination mentioned above, Windle and Becker also compared the post-natal behaviour of the resuscitated and control guinea pigs. They found that the asphyxiated animals lost more weight in the first 3 days post partum than did the controls as well as exhibiting symptoms of neural damage such as tremors, paralysis, convulsive twitching etc. The asphyxiated group also exhibited noticeable behavioural differences; they were not disturbed by environmental change, they remained docile when handled, they were less active than the controls and many presented feeding problems. In a maze learning situation, the asphyxiated animals made more errors and repeated their errors more frequently than did the controls. Similarly in kittens, Meier (1954) demonstrated differences in discrimination learning between those animals undergoing anoxia immediately prior to and during the birth process compared to normal animals and he suggested that brain function in the asphyxiated animals had been impaired.

iii. Changes in foetal blood flow patters

Experiments have indicated (Campbell, Dawes, Fishman and Hyman,

1967) that partial asphyxia of mature foetal lambs produced a rise in arterial blood pressure with corresponding decreases in femoral and renal blood flows but increases in coronary and cerebral flows. The authors concluded from this that the foetal lamb must be capable of controlling vasomotor tone by reflex means.

As a result of his work on piglets, Randall (1978) thought that the foetus would normally be able to overcome most of the effects of intermittent hypoxia during the initial uterine contractions of birth and he suggested that the foetal aortic chemoreceptors might receive intermittent stimulation during contractions which would give rise to peripheral vasoconstriction and increased placental blood flow i.e. the foetus has some control over the pattern of blood flow.

Stave (1970) listed various compensatory mechanisms which he claimed became active if umbilical blood flow is compromised:

1. Lower oxygen tensions in the umbilical vessels will create a larger diffusion gradient from mother to foetus, which in turn will favour transfer of materials into the foetus.
2. In early acute hypoxaemia, there ia a rise in foetal arterial blood pressure which should promote increased umbilical blood flow.
3. A redistribution of blood flow occurs with preference being given to vital organs such as the brain, heart and placenta.

These changes in blood flow patterns may also affect the respiratory system for Dawkins (1966) suggested that anoxia initiates vasoconstriction of the pulmonary blood vessels which severely reduces pulmonary blood flow. He claimed that, since the ductus arteriosus does not close in the presence of low pO_2, this vascular shunt from right to left in the heart remains open and blood needed for gas exchange is diverted from the lungs. He also proposed that inspiration of amniotic fluid coupled with low pulmonary blood flow may lead to a loss of pulmonary surface active phospholipid which would further complicate lung expansion.

iv. Other effects

Acute hypoxia serves to activate the sympathetic nervous system, for when Comline and Silver (1958) ligatured the umbilical cords of lamb foetuses, they observed that large amounts of adrenalin and noradrenalin were released. In a further study (Comline, Silver and Silver, 1959), they also noted decreases in pO_2 and pH but increases in pCO_2 and lactic acid on application of the ligature. They concluded that it was the decline in pO_2 which caused the secretion of hormones from the adrenal medulla, with noradrenalin being secreted first, followed by adrenalin. A comparison of arterial pO_2 values in these experiments and in normal lambs caused them to claim that, in the lamb, there is only a slight margin between resting pO_2 levels at the end of pregnancy and those pO_2 levels which form the threshold for the discharge of hormones from the adrenal medulla.

The effect of acute hypoxia in causing the depletion of cardiac glycogen has already been mentioned but an effect of hypoxia on brain cells has also been noted (Dawes, 1968), in that when glycolysis ceases due to a lack of substrate, there is still a continuing fall in extracellular pH. Eventually the cells begin to suffer from the osmotic effects of lactate accumulation and from the lack of energy which is needed to maintain the ionic gradient across the cell membrane. This causes swelling of the mitochondria and eventually the lysosomes release their protease enzymes and self destruction proceeds. Such adverse effects on brain functioning could easily account for the behavioural changes mentioned earlier.

5.7 Acidosis

Asphyxiation also results in the production of a state of acidosis which can be subdivided into respiratory and metabolic types. Respiratory acidosis refers to a primary increase in pCO_2 as carbon dioxide is not removed, while metabolic acidosis refers to a decrease in the base buffer content of blood, due to the effects of increasing anaerobic respiration (Singer and Hastings, 1948; Swann, Christian and Hamilton, 1954). The 2 conditions frequently overlap as James et al (1958) showed in their experiment when a brief period of anoxia produced a respiratory acidosis in the foetus (i.e. increased blood pCO_2 levels), but in the case of a more prolonged period of anoxia, a metabolic acidosis was superimposed on this. Such changes can greatly affect blood pH values as Randall (1979) demonstrated in his work on pig foetuses; preasphyxiation blood pH was 7.43 but this dropped to 6.66 post asphyxiation.

The development of an acidotic state is particularly important during parturition and in humans Vedra (1960) has stated that a protracted labour produces a state of maternal metabolic acidosis due to accumulation of lactic acid and the more prolonged the labour, the more severe will be the acidosis. He also showed that the degree of maternal acidosis can affect the extent of foetal acidosis as it affects the oxygen dissociation curve which lowers oxygen saturation in umbilical vein blood. Daniel, Adamsons and James (1966) also claimed that as labour progresses, the foetus becomes increasingly acidotic due primarily to a reduction in uterine blood flow as a result of contractions.

In pigs, Randall (1972e) demonstrated how blood pH changes over the first 24 hours in normal piglets (table 5.2). The rise in pH over the first 10 minutes of life can be associated with the loss of carbon dioxide which occurs primarily in the first 2 minutes post partum as a result of irregular gasping and rapid shallow panting causing hyperventilation. Randall also quoted unpublished data which showed that the pH of normal pigs (i.e. a viability score of 10) was slightly lower in the later stages of parturition than in the earlier stages and he claimed that this was acidosis resulting from the uterine contractions.

Table 5.2 Changes in blood pH during the first 24 hours post-partum

	pH
Before the onset of respiration	7.312
10 min. after " " "	7.345
30 " " " " "	7.326
24 hr. " " " "	7.439

(Randall, 1972e)

Other work involving analysing the blood of newborn piglets (Wilhelm, 1975; Wilhelm, Maurer-Schweizer and Walser, 1977) has indicated that they are born with a mixed respiratory and metabolic acidosis; the respiratory acidosis improves within 1 hour of birth, but the metabolic acidosis deteriorates before returning to normal. In a further study (Wilhelm, Maurer-Schweizer and Walser, 1978), they investigated the effects of the period between successive births (i.e. birth interval) on blood pH; piglets were divided into 3 groups depending on the interval between their delivery and the previous one:

Group 1	Group 2	Group 3
0-9 mins.	10-30 mins.	>30 mins.

Their results showed that the piglets in group 3 had a lower blood pH value in the first 10 minutes after birth than did the other 2 groups which, they claimed, was due to the development of a more marked metabolic acidosis.

5.8 Asphyxia as a cause of stillbirth

Several authors e.g. Randall (1971) and Randall and Penny (1967) have claimed that asphyxia during parturition is an important factor in the aetiology of stillbirths, and in his 1979 study, Randall found similar biochemical changes in the blood of stillborn pigs as in ones which had been asphyxiated. It has been stated (Wrathall, 1971) that acute or subacute anoxia is usually the immediate cause of intrapartum stillbirths while Schnurrbusch and Elze (1981) claimed that hypoxia due to the premature rupture of the umbilical cord causes the majority of stillbirths and Sprecher

et al (1975) also claimed that many intrapartum stillbirths result from hypoxaemia caused by premature umbilical rupture or impeded umbilical blood flow and this leads to irreversible brain damage. A time limit has been placed on this by Curtis (1974) who claimed that there is irreversible brain damage within 5 minutes of umbilical rupture or impedance of umbilical blood flow. Others e.g. Bjorklund (1981) have agreed that if the time between the breaking of the umbilical cord and the piglet taking its first breath exceeds 5 minutes, incurable brain lesions result. He considered that this was most common in old sows having large litters with protracted intervals between successive births and he quoted in support of his hypothesis the fact that over 80% of all stillbirths occur in the last third of the farrowing order.

In 1974 Curtis reviewed the literature to show that stress from the prenatal respiratory gas environment is directly related to intrapartum stillbirths and reduced neonatal viability. He claimed that birth is a time of abrupt and profound environmental change - from a parasitic intra-uterine existence to an independent extra-uterine one, as after birth the piglet has to breathe for itself. The major circulatory and respiratory changes involved occur within 10 seconds of delivery - the lungs are inflated, an adequate pulmonary circulation is established and exchange of respiratory gases begins.

During farrowing, blood pO_2 falls and pCO_2 rises, due to a reduced respiratory gas exchange between foetus and placenta. The placental

blood flow drops during uterine contractions and the placenta may become partly detached from the uterus, in addition to the umbilical cord possibly becoming compressed or rupturing. Blood pCO_2 is normally the main feedback in the control of breathing and if it rises, this causes an increased rate of breathing. If, however, blood pCO_2 is very high and pO_2 very low, the mechanism does not work properly and the central chemoreceptors in the medulla are depressed. Peripheral chemoreceptors (e.g. carotid bodies) are not depressed by hypoxia however and they function normally to produce breathing movements i.e. severe prenatal asphyxia results in foetal gasping.

The foetus generally withstands hypoxia longer than the adult (Fazekas et al, 1941) and it attempts to meet its energy needs by anaerobic metabolism of carbohydrate stores (Dawes, 1965, 1968) but it can only survive as long as glucose is available to the tissues and blood pH remains in the normal range. The survival time of a piglet under hypoxia is short and the time to irreversible brain damage even shorter.

In conclusion, the weight of the available evidence suggests that asphyxia is an important factor in the aetiology of stillbirths but as Bjorklund (1981) observed, although 94% of stillborn pigs had ruptured umbilical cords at delivery, some pigs were born alive with ruptured cords while others are born dead with intact cords or after only a short birth interval i.e. there must be other factors involved as well. In his 1968 study, Randall stated that it seemed "probable that the contributing causes of anoxia in the pig are multiple so that a factor resulting in the delivery of a stillborn piglet in one litter, may not necessarily do so in another, or in other parts of the same litter".

5.9 Asphyxia as a cause of depressed viability at birth

An investigation has been carried out (Bjorklund, 1981) in which umbilical cord lactate levels were measured in a large number of newborn piglets and after 3 weeks, values from animals that had died were compared with those still living. The dead piglets had mean blood lactate levels that were 26.5% higher than the animals still living and so he concluded that hypoxia can contribute to the production of weak animals. Randall (1968) obtained similar results and came to the same conclusion. Likewise Svendsen and Bille (1980) claimed that the pig is very susceptible to hypoxia and that intrapartum asphyxia is associated not only with perinatal mortality but also with postnatal morbidity. They stated that liveborn piglets which had suffered from asphyxia during delivery often showed lowered viability for several hours post partum and that this endangered their ability to survive throughout the entire neonatal period. Other authors e.g. Randall and Penny (1967), Randall (1971) and English and Smith (1975) have also claimed that factors (such as asphyxia) which lead to intrapartum stillbirths will also result in decreased viability of liveborn pigs and it has also been suggested (Schnurrbusch and Elze, 1981) that piglets which have been weakened by asphyxia during farrowing are more prone to neonatal virus diseases.

Dawkins (1966) described how anoxia during birth may upset the already inefficient heat producing mechanisms and this results in a rapid fall in body temperature in a cool environment. Continuing hypoxia after birth complicates the problem, so that laterborn piglets could be at a particular disadvantage. It has also been

postulated that the thermoregulatory centre in the brain could be affected by anoxia which would mean that newborn piglets would be particularly susceptible to chilling (Stanton and Carroll, 1974). These authors speculated upon the effects of intrapartum anoxia on depression of central nervous system activity. They considered that this would be serious if piglets were to be born lethargic and disorientated, so that they did not compete with their littermates for milk but instead remained under the heat lamp without suckling.

Some of the depression in viability at birth may be due to inhibition of medullary respiratory reflexes caused by hypercapnia (high carbon dioxide levels in blood) according to Stanton and Carroll (1974). They explain however that a pig which is born hypercapnic is not dead but rather, it can be saved by the artificial application of air. As many as 25% of the piglets born "apparently dead" have been revived (Milosavljevic et al, 1972).

5.10 Assessment of viability in neonates

It is often necessary within the field of animal production as well as medicine, to be able to assess the viability of a neonate. Since speed is obviously vital in any such assessment, many techniques make use of blood parameters such as lactic acid levels.

i. Use of lactic acid level

Several authors e.g. Pettigrew, Zimmerman and Ewan (1971) and Meyer, Kroger and Sagel (1976) have found higher lactate levels in underweight neonatal pigs. The former authors speculated that this could mean that heavier pigs were less subject to hypoxia or

that they were more resistant to it, but they observed, however, that the lactate level at birth was not apparently related to subsequent performance.

The use of lactic acid levels to indicate asphyxia (and thus depressed viability) has been known for over 50 years; in 1931 Eastman and McLane stated that "lactic acid is the characteristic product of anaerobic metabolism in the animal body and its accumulation constitutes our most reliable indication of oxygen deficiency". In the conclusion to his literature review of indicators of asphyxia, Randall (1968) noted that oxygen saturation levels in umbilical cord blood have been shown to bear little relation to the oxygen status of the foetus in utero and that respiratory acidosis has been shown to develop rapidly under short periods of acute anoxia. He considered that blood pH was a good indicator of foetal asphyxia, but it had the disadvantage of being affected by both respiratory and metabolic acidosis. In view of this and also because it is a measure of the degree of anaerobic metabolism as well as being a stable compound, Randall decided to use blood lactic acid levels in newborn pigs as an indicator of intra-uterine asphyxia.

Some experimental results from a range of species which indicate the relationship between blood lactic acid levels, degree of asphyxiation and viability are shown in table 5.3.

In pigs, Randall has carried out several investigations into the relationships between blood lactic acid levels and other possible indicators of viability such as state of the umbilical cord at birth, degree of meconium staining and time interval preceding

Table 5.3 The use of lactic acid levels to indicate viability

Author and Year	Results/Conclusions
a) Human Infants	
Daniel, Adamsons & James (1966)	Higher lactate levels in depressed infants compared to vigorous ones.
Eastman & McLane (1931)	Found a correlation between level of lactate in umbilical cord blood and clinical state of infant i.e. fatally asphyxiated infants had significantly higher lactic acid levels.
James & Burnard (1961)	Depressed infants had higher lactic acid levels at birth.
Raiha (1963)	Depressed infants had higher lactic acid levels at birth.
b) Lambs	
Barker and Britton (1958)	When a state of hypoxia was produced in the foetus, blood lactic acid levels rose by 7 mg/100ml/min.

Table 5.3 continued

Author and Year	Results/Conclusions
Brandt, Harned & Cooke (1958)	Lactic acid levels before asphyxiation were 10-32 mg/100ml, after asphyxiation this rose 11 fold.
Britton, Nixon & Wright (1959)	Lactic acid levels in fatally asphyxiated foetal lambs were 290 mg/100ml, in control animals values were 100 mg/100ml.
c) Pigs	
English & Smith (1975)	Lactic acid values in liveborn pigs at birth were 383 µg/ml in those pigs which died before 3 weeks, but only 303 µg/ml in pigs which survived.
Pettigrew et al (1971)	Lactic acid levels in normal newborn pigs were 79 mg/100 ml. Laterborn pigs had higher concentrations.
Randall (1979)	Near term foetuses before asphyxiation had 40 mg/100ml, after asphyxiation this rose to 186 mg/100 ml. Stillborn pigs had 159 mg/100 ml.
Randall & Penny (1968)	Liveborn pigs had lactic acid levels of 34 mg/100ml, stillborn pigs had 159 mg/100 ml.
Stanton, Brown & Mueller (1973)	Elevated blood lactate levels were positively associated with stillbirth or depressed viability at birth. Piglets with highest levels of lactate suffered greatest temperature loss at 5°C.

delivery. In his 1968 study, he reported that lactic acid levels in pigs born with ruptured cords were 40 mg/100ml whereas those in pigs born with intact cords were 36 mg/100ml, the difference being non significant. He also found positive correlations between lactic acid levels and degree of meconium staining and lactic acid levels and time interval preceding delivery, although again these were not statistically significant.

He did, however, find a highly significant difference in lactic acid levels between normal piglets born in the first and third parts of the litter (table 5.4).

Table 5.4 Relationship between lactic acid level and position in litter

Portion of litter	Mean lactate levels (mg/100ml)	S.E.
First	29.1 **	± 1.65
Second	35.2	± 2.60
Third	48.2 **	± 3.83

** $P < 0.01$ (from Randall, 1968)

The high lactic acid levels found in piglets born in the last third of farrowing could be due either to an increase in the anaerobic metabolism of these piglets or to diffusion of exogenous lactic acid into the foetus. If the latter possibility had been correct, Randall considered that there would have been similar results in the first two thirds of farrowing, but the variation in lactic acid level here was virtually constant whereas variation in the last third was 4 times as high. Authors

such as Hendricks (1957), Daniel et al (1966) and Bossart, Von Niederhausen, Rey and Weihs (1968) have all shown that there is an increase in plasma lactate during labour which has been attributed to maternal muscular activity, at least in women, (Hendricks, 1957). Derom (1964) found higher lactate levels in women with prolonged labour and Randall (1968) considered it possible that the higher levels in the laterborn piglets could reflect the higher maternal lactic acid levels.

In order to be able to relate lactate levels to piglet viability, Randall devised a scheme for assessing viability based on the quality of respiration at birth and the piglet's attempts to stand (table 5.5).

Table 5.5 Classification of viability in newborn piglets

Class 0	No evidence of viability.
Class 1	Evidence of cardio-vascular function at birth but no respiratory efforts.
Class 2	Severely depressed piglets had difficulty in establishing respiration at birth and were dyspnoeic for at least 5 minutes after recovery. Slow in attempting to stand and in suckling successfully.
Class 3	Mildly depressed piglets - had no difficulty in establishing respiration but took longer to stand and were unsteady for a longer period than normal piglets.
Class 4	Normal piglets. Had no difficulty in establishing respiration and were usually standing within one minute and were active in finding a teat.

(Randall, 1968)

Using this classification, Randall found a highly significant difference in lactic acid levels between piglets of class 4 and classes 1, 2, and 3 (table 5.6).

Table 5.6 Relationship between lactic acid levels and viability scores

Class	Mean lactic acid level (mg/100 ml)	S.E.
1	159.3	± 15.1
2	138.5	± 15.1
3	56.1	± 5.9
4	34.0	± 1.5

(Randall, 1968)

ii. Use of blood pH level

Little use has been made of this in piglets, although Randall (1971) found that piglets with lower viability scores (as derived from his classification described above) had a significantly lower blood pH level. Most of the work on blood pH has been carried out in human infants, but the general trend of the results is to agree with Randall i.e. depressed infants have a lower blood pH (James et al, 1958; James, 1960; James and Burnard, 1961; Beard, Morris and Clayton, 1967; Wood, Ferguson, Leeton, Newman and Walker, 1967).

iii. Use of blood pO_2 level

According to James (1960), this is very labile and so it cannot be taken as a reliable guide to the state of the foetus at birth. Little correlation has been found between foetal pO_2 levels and viability scores as determined by other techniques. In addition, they reported that infants may make initial respiratory gasps with no measurable oxygen in their arterial blood i.e. the oxygen saturation of the umbilical artery correlates poorly with postnatal vigour.

iv. Use of other techniques

Mention has already been made of Randall's (1968) system of classifying the viability of piglets; the other system which has been in frequent use over the years was devised by Apgar, Holaday, James, Weisbrot and Berrien in 1958. It is an objective scoring system for assessing the viability of newborn infants based on heart rate, promptness and vigour of first respiratory efforts, reflex responsiveness, muscle tone and colour. The highest possible score is 10 (which represents the optimum condition) whereas the lowest score (denoting total non-viability or death) is 0. Apgar et al considered that heart rate and respiratory efforts are much more important than muscle tone and reflex irritability and that colour is the least important parameter. From their results, they observed that the lowest scores are generally associated with chemical findings characteristic of asphyxia and that there is a close correlation between the lowest scores and the highest neonatal death rate. DeRoth and Downie (1976) also made use of a similar scoring technique when assessing the viability of newborn piglets in their first minute of extra-uterine life and like Apgar et al, they considered heart rate and respiration to be the most important parameters. However, they also included the attempts of the piglet to stand and they claimed that this was a good indicator of the final score. From their results they observed a significant ($P < 0.05$) correlation between a low viability score of 1-5 and the death rate in the first 10 days post partum. These low viability pigs had a significantly ($P < 0.005$) lower birth weight than the more viable pigs (0.9 kg v. 1.2 kg) and the authors postulated

that these underweight animals do not recover from the physiological trauma of birth as well as normal pigs, so that a high birthweight and a rapid farrowing (to minimise dangers from asphyxia) are desirable in a commercial situation.

Chapter 6

ASPECTS OF PIGLET IMMUNOLOGY

6.1 Introduction

As the survival of the newborn piglet is dependent upon the rapid establishment of a state of immunity and the acquisition of antibodies, it is pertinent to attempt to answer the question "what are antibodies?" They have been described by Brambell (1958) as being molecules of soluble proteins which are adapted to react specifically with foreign substances known as antigens. In a later publication (Brambell, 1970), he went on to explain that antibodies are very specific and only react with the particular kind of antigen which stimulated their production, or with a closely related one which has a similar antigenic structure. There are various types of antibodies which are named according to their mode of interaction with the antigen e.g. lysins, agglutinins, opsonins, precipitins and antitoxins.

Antibodies are present within the plasma protein fraction of blood; the plasma proteins can be divided into 4 groups - albumins and the α, β & γ globulins which can be characterised and separated by various physical and chemical procedures (Brambell, 1958). Methods such as electrophoresis have shown that antibody activity is limited to the globulin fraction and in particular to the β and especially the γ globulins (Herbert, 1970). According to Martinsson (1970), the term γ globulin was introduced by Tiselius in 1937 for the plasma proteins which

moved most slowly in an electric field, but nowadays the term "immunoglobulin" is preferred for globulins which show antibody activity since antibodies are not only found in the γ globulin fraction.

Webb and Goodman (1967) described immunoglobulins as being a heterogeneous group of substances which have a common structural unit (a combination of 1 light and 1 heavy chain) and this is probably the essential element in the reaction between an immunoglobulin and its corresponding antigen. Bourne (1971b), however, stated that immunoglobulins were multi-chain proteins made up of 4 polypeptide chains - 2 light (i.e. low molecular weight) and 2 heavy (i.e. high molecular weight). The light chains are found in all immunoglobulin classes whereas the heavy chains are specific and determine to which class the immunoglobulin belongs; while the variations in the amino acid sequences in the proteins gives rise to the various subclasses. According to Porter (1973) it was due to the World Health Organisation in 1966 that the standard nomenclature was adopted internationally i.e. IgG, IgA, IgM etc.

6.2 Acquisition of immunity in the newborn piglet

i. Active immunity

In the newborn piglet, as in all other mammals, a state of immunity can be acquired actively i.e. the piglet itself starts to produce antibodies in response to the presence of antigens. In fact several workers claim to have demonstrated a capacity for antibody production in the pig foetus as early as the 55th day of gestation (Bourne, Curtis, Johnson and Collings, 1974) or the 75th day (Solomon, 1971). Likewise Sterzl, Kostka, Mandel, Riha and Holub (1960) and Redman (1979) claimed to have found evidence of antibody production in the

foetus while Prokesova, Rejnek, Sterzl and Traviecek (1969) found some actively synthesised immunoglobulins in the serum of newborn piglets, although they were only present in very low concentrations. Work done by Chaniago, Watson, Owen and Johnson (1978) showed that some (24 out of 1147) foetuses had detectable levels of IgG or IgM in their serum but not IgA. They reasoned that this could have been due to a damaged placenta and leakage of maternal antibodies, but as in several piglets there were measurable quantities of IgM but no IgG, they thought it improbable that leakage of one would have occurred without the other and so they concluded that these immunoglobulins had been produced by foetuses in response to the presence of specific antigens. Likewise Kim, Bradley and Watson (1966) found a good antibody response when newborn pigs were injected with antigen. More usually, however, the low level of antibody synthesis even in the first days after birth is the main problem associated with the dependence of the newborn piglet on active acquisition of immunity and as Franek, Riha and Sterzl (1961) showed, newborn pigs can only synthesise minute quantities of immunoglobulins and this is not enough to allow maturation of the serum protein profile sufficiently quickly. Bourne (1973) agreed, claiming that although antibody containing cells appear about 10 days after birth, the levels of circulating immunoglobulin are so low that the piglet requires another form of protection for the first few weeks. It seems that, although the young piglet can produce antibody during the first week of life in response to a powerful antigenic stimulus, 3 weeks after birth is a more normal time for active immunisation (Brambell, 1970).

ii. Passive immunity

Since the mammal in utero is sheltered from most antigenic stimuli, the newborn mammal usually lacks active immunity and would have little ability to resist disease if it was not able to acquire immunity passively from its dam. The passively transferred antibodies persist for longer in the circulation of the young animal than they do in that of an adult and so they help the newborn animal to survive over this period until it is able to increase its own capacity for producing antibodies i.e. this transmission of passive immunity from dam to young plays a vital role in neonatal survival (Brambell, 1970).

Depending on species, this transmission of antibodies may occur either pre or postnatally, but in the pig it only occurs after birth. The reason for this according to Bourne (1969c) is that the sow has an epitheliochorial type of placenta characterised by the persistence of the uterine epithelium and it is this factor which determines the impermeability of the placenta to large protein molecules so that in the sow there is no transmission of antibodies from dam to foetus which means that transmission has to take place immediately after birth via the medium of colostrum. The transmission of immunity to neonatal pigs via colostrum has been known for a long time; Pierce (1962) quoted Ehrlich in 1892 as being the first to appreciate colostral transfer of maternal antibody while in 1919 McArthur vaccinated sows against hog cholera and then tested the immunity of the offspring by exposing them to the virus. As a result of this work he showed that the offspring of immunised pigs had a high degree of immunity while they were still suckling, but that this immunity was gradually lost after weaning. Further research by Connaway (1922),

Nelson (1932) and Earle (1935) also confirmed colostral transfer of antibodies.

Colostrum itself has been defined by McGirr (1947) as a glutinous emulsion secreted in greater or lesser amounts by the mammary glands in all animals in the period immediately following parturition. The outstanding feature of colostrum is its high protein content and particularly the globulin fraction; Morris (1968) quoted a concentration of 16% β globulins and 39% γ globulins in colostrum, and described how the globulin fraction is concentrated within the mammary gland to produce levels in colostrum which are several times higher than in blood plasma at parturition; in other words, there is a selective transfer of globulins into the secretory cells of the mammary gland.

With specific reference to the pig, Porter (1969) stated that the major immunoglobulin in porcine colostrum is IgG and quoted values of 80% IgG, 14% IgA and 6% IgM. Martinsson (1970) agreed that IgG is the predominant colostral immunoglobulin and likewise Bourne (1971b) who claimed that the IgG content of colostrum accounts for over 80% of the total immunoglobulin content.

Bearing in mind the very limited amount of antibody synthesis in the neonatal pig in addition to the impermeability of the placenta to antibodies, one would expect to find negligible antibody levels in the plasma of newborn pigs before suckling and this has indeed proved the case (Asplund, Grummer and Phillips, 1962; Binns, 1968; Hoerlein,1952, 1957; Jakobsen and Moustgaard, 1950; Lecce and Matrone, 1960; Lecce, Morgan and Matrone, 1964; Porter, 1969; Rook, Moustgaard and Jakobsen, 1951, Rutqvist, 1958; Young and Underdahl, 1949, 1950). All these workers however, reported a rapid increase in antibody levels after suckling. The results of workers

such as Kim, Bradley and Watson (1965), Miller, Ullrey, Ackerman, Schmidt, Hoefer and Luecke (1961), Nordbring and Olsson (1957) who claimed to have found evidence of antibody activity in pre-colostral serum from pigs may be explained on the basis of a damaged placenta, actively synthesised antibody or the use of techniques which were not sufficiently sensitive to distinguish immunoglobulins from other proteins present.

6.3 Mechanism of immunoglobulin uptake

The absorption of antibodies in the pig takes place entirely within the small intestine and the antibodies are transferred to the circulation by way of the lymph vessels (Brambell, 1958). He described how antibodies appeared in the lymph within 1-2 hours of introducing colostral whey into the duodenum (provided that this was within 27 hours of birth) and histological examination showed the presence of globules of protein in the intestinal epithelial cells in these animals. Likewise, Sibalin and Bjorkmann (1966) observed that when newborn pigs are fed with colostrum, there is a dramatic increase in the vacuoles and vesicles in both apical and basal parts of the cell. The vesicles and vacuoles contained a foamy material (which they suggested was colostrum) and this was also present in the dilated intercellular spaces. After 2 days, there was a marked decrease in the size and number of vacuoles, while the intercellular spaces had become smaller and they proposed that these changes were related to the period of maximum immunoglobulin uptake.

Similarly, Staley, Jones and Corley (1969) observed that the duodenal cells of the newborn piglet are like those of the adult but, on receiving colostrum, they rapidly developed large protein and lipid filled vacuoles and a complex tubule system at the apical end of the cell. The protein accumulated in bulb-like enlarge-

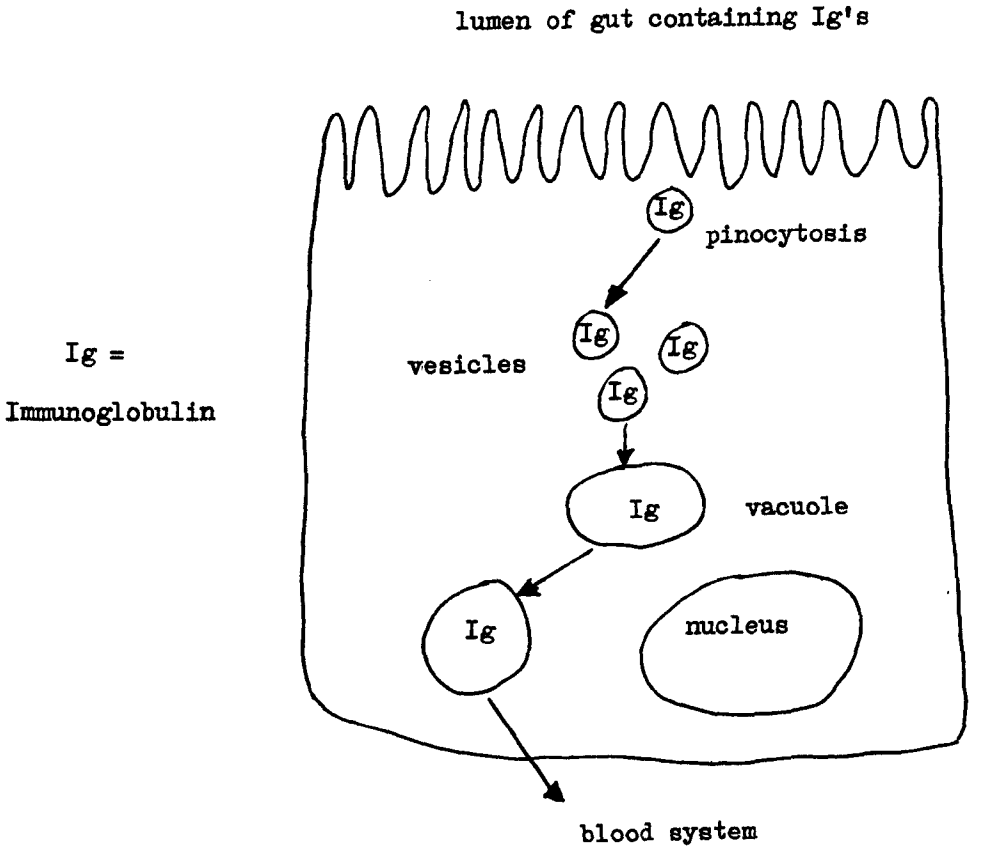
ments of the ends of the tubules which in turn became detached to form vacuoles. The appearance of the cells after 16 hours suggested that protein passed through the tubules of the Golgi apparatus and was discharged into the intercellular spaces. By the time the piglet was 48 hours old, its duodenal cells had lost these characteristics and had returned to a condition resembling the adult again. It has been suggested that the functional changes in the brush border surface of the newborn pig intestine are connected with its absorptive function at this stage (Smith, Munn, Burton and deJesus, 1975).

Concerning the actual mechanism by which large immunoglobulin molecules are taken into the intestinal cells, Comline, Roberts and Titchen (1951) were among the first to propose the mechanism of pinocytosis. Clark (1959) agreed and described invagination of the apical cell membrane to form vacuoles containing material from the intestinal lumen. It seems probable that all transfer of maternal antibody into the intestinal cells involves pinocytosis and that the infolding of the cell membrane can be so extensive that sometimes the membrane is carried deep inside the cell where isolated vesicles containing maternal antibody can be seen around it (Solomon, 1971).

Kraehenbuhl and Campiche (1969) studied intestinal absorption of antibodies in a range of species including the newborn pig. They described how proteins are taken up by pinocytosis into the jejunal cells and how vacuoles are formed by the fusion of vesicles. Vacuoles are progressively transferred into the basal

cytoplasm of the cell without interference by other cell organelles and they are discharged from here to enter the circulation (fig. 6.1)

Fig. 6.1 Schematic representation of a jejunal absorptive cell during antibody absorption in the newborn pig



(from Kraehenbuhl and Campiche, 1969)

Immunoglobulins were first found in the circulation 15-30 minutes after being injected into the intestine and the authors proposed that this indicated that they are transferred directly into blood capillaries, possibly after discharge of the epithelial vacuoles in the interstitial space. The blood capillaries are located close to the epithelium and the endothelium which lines them has fenestrations which may facilitate macromolecule uptake. They

claimed that vacuoles containing antibodies were frequently seen in the endothelium of the lymphatics but only rarely in the endothelium of blood vessels and they concluded that the mechanism by which vacuoles are transferred from epithelial cells to connective tissue cells and lymphatic endothelium is uncertain.

There is some evidence that the uptake of immunoglobulins requires energy as Bamford (1966) carrying out in vitro studies on rat intestine reported an increase in oxygen consumption as proteins were absorbed and Lecce (1966b) working on pig intestine observed that immunoglobulin absorption was inhibited by metabolic poisons.

6.4 Rate of immunoglobulin absorption

i. Mechanism of gut closure

Various workers have studied the rate of immunoglobulin absorption (table 6.1). Although the precise figures vary somewhat, the table shows clearly that antibodies are absorbed rapidly after birth and that the period of absorption is a relatively short one, approximately 24 hours. After this time, the gut appears to undergo a change so that it is no longer permeable to the large immunoglobulin molecules (table 6.2). The time at which gut closure takes place appears to depend on the diet being fed as table 6.3 shows.

In an attempt to explain these results, Lecce (1973) proposed that the maturation of both phases of absorption (i.e. uptake of macromolecules and their subsequent transport into the blood) is affected by dietary regime, although the processes themselves are independent. Starved piglets continued to transport internalised

Table 6.1 Rate of immunoglobulin absorption in newborn pigs

Author and Year	Results/Conclusion
Kelley (1977)	Piglets have 1mg immunoglobulin/ml serum at birth, but this increases to 40 mg/ml at 12 hours.
Miller et al (1961)	% γ globulin in serum increases from 6.5% at birth to 46% (maximum) at 24 hours.
Morris (1968)	Absorption continues for 24-36 hours but greatest part has been absorbed by 12 hours after birth.
Owen and Bell (1964)	Bulk of absorption is over by 12 hours after birth.
Payne and Marsh (1962a)	Used fluorescein labelled γ globulins and took sections of intestine at hourly intervals after feeding which showed that the epithelial cells began to absorb almost immediately and that the maximum content of cellular immunoglobulins was reached 6-7 hours after feeding.

Table 6.1 continued

Author and Year	Results/Conclusion
Perry (1964)	Delaying the administration of antibodies to piglets reduced the amount absorbed by 2% per hour.
Perry and Watson (1967a)	Dosed piglets with antibody at known time intervals after birth. Up to 6 hours after birth the efficiency of abosrption was 10.8%, which then increased to 14.5% at 12 hours and decreased to 5.4% at 24 hours.
Ramirez, Miller, Ullrey and Hoefer (1963)	Massive absorption of β & γ globulins over the first 24 hours of life.
Speer, Brown, Quinn and Catron (1959)	Very rapid absorption over first few hours of life followed by a rapid decline so that absorption was insignificant after 24 hours.
Wu, Wang and Chang (1980)	Antibodies appeared in blood as early as 3 hours after ingesting colostrum and reached maximum level 9-24 hours later.
Young and Underdahl (1949, 1950)	Antibody absorption reached maximum level 6 hours after suckling and remained at this level for up to 72 hours.

Table 6.2 Estimates of time of gut closure in piglets

Author and Year	Time of gut closure
Asplund, Grummer and Phillips (1962)	21 - 27 hours post partum
Hardy (1969a)	24 - 48 hours post partum
Harmon, Becker and Jensen (1963)	30 - 40 hours post partum
Lecce (1972)	18 - 24 hours post partum if proteins fed or injected into gut lumen but absorptive capacity (rather than capacity to transport proteins into blood) is still apparent at 1-3 days post partum in the duodenum and upper jejunum, while in the lower jejunum and ileum it is 14-18 days.
Miller, Harmon, Ullrey, Schmidt, Luecke and Hoefer (1962)	24 - 36 hours post partum

Table 6.3 Effect of dietary regime on gut closure

Author and Year	Results/Conclusion
Anon (1962)	Absorption of γ globulins had ceased after 12 hours of feeding cow's milk or sow's colostrum to newborn piglets, but in pigs which were only fed water, absorption continued for 106 hours after birth.
Bourne (1969c)	Ability of newborn pig to absorb immunoglobulins from colostrum lasts for 24-36 hours but if the pigs are fed electrolyte solutions or are starved, the gut may remain permeable for as long as 5 days.
Lecce and Morgan (1962)	When 300-400 cm^3 cow's colostrum was fed to newborn piglets, it caused the closure of the gut in 24 hours but when piglets were only fed water, absorption was still occurring after 86 hours.
Nordbring and Olsson (1958)	Fasted pigs can absorb γ globulins up to 72 hours after birth.
Payne and Marsh (1962b)	When pigs were fed only water, there was still a marked absorption of γ globulin after 106 hours, but when they were fed colostrum, absorption ceased after 12 hours.
Zintzen (1974)	Ingestion of milk leads to gut closure within 36 hours.

macromolecules into the blood in the same manner as newborn pigs, whereas fed pigs did not. Also, starved pigs continued to internalise protein within the gut epithelium whereas the intestinal epithelium from 3 day old piglets either fed artificially 24 times a day or allowed to suckle normally, lost about 60% of its uptake capacity. According to Lecce, this closure began at the duodenum and proceeded towards the ileum as the piglet aged, so that by 3 weeks of age, the whole gut has closed.

Several workers have made use of the inert macromolecule polyvinylpyrrolidone (PVP) in their studies on gut closure. Lecce and Morgan (1962) used PVP to indicate the capacity of the gut to absorb γ globulin and found that it was readily absorbed up to 86 hours post partum whereas Hardy (1969a) showed that PVP absorption ceases shortly after birth while Clarke and Hardy (1971) reported that the uptake of labelled PVP can persist for up to 14 days post partum i.e. long after the gut has become impermeable to antibodies. The latter authors suggested that closure of the pig intestine occurs in 2 stages; initially the intestine is lined with cells that take up PVP from the gut and transfer it to the lacteals but soon after birth, these cells are replaced by others which, although they retain their pinocytotic ability, can no longer extrude intracellular PVP (and so presumably other macromolecules) into the lacteals. Finally, these cells are replaced by others which can no longer take up the macromolecules. Clarke and Hardy claimed that this sequence of cellular replacement can be related to the histological changes which take place in

different regions of the piglet small intestine during the first 3 weeks of life. It is perhaps debatable as to whether the precise timing of Clarke and Hardy's hypothesis would correspond to that of El-Nageh (1967) who suggested that the absorptive capacity of the intestinal epithelial cells decreases with each succeeding generation of cells and that the aptitude for pinocytotic uptake of protein is lost after 1 or 2 replacements of the intestinal epithelium but, as a general hypothesis, it would seem to be acceptable.

Lecce has been one of the most prominent researchers in the field of gut closure and as a result of his early work (Lecce and Morgan, 1962), he proposed that the quantity of colostrum consumed appeared to be the determining factor in bringing about closure. Gut closure can be brought about by non protein materials such as glucose and the capacity of a diet to diminish absorption appears to be more dependent on numbers of molecules rather than types of molecules (Lecce, 1966a). Lecce postulated that if pinocytosis proceeds by the interiorisation of the surface membrane, it is probable that the absorptive capacity would be limited by the luminal surface of the epithelial cell and so closure would occur when the critical surface area is used up. He thought it possible that many different kinds of molecules (both large and small) could stimulate the surface membrane to form pinocytotic vesicles which would lead to exhaustion of the membrane. If large molecules are present during this process, they would be absorbed but even if they are not present, the membrane would still become exhausted.

This hypothesis would mean that the absorption of large molecules and closure are independent phenomena as Lecce, Morgan and Matrone (1964) had shown. Lecce (1966a) also proposed that the time required for closure is directly related to the number of molecules confronting the cell. It has been suggested (Broughton and Lecce, 1970) that the plasmalemma of the intestinal cell is capable of forming a certain number of pinocytotic channels and no more, so that when this number is reached, gut closure occurs. They related this in turn to diet as those diets which are known to induce closure (such as colostrum) stimulate intense pinocytotic activity in gut epithelium whereas other dietary regimes (such as salt solution or water only) induce little or no pinocytotic activity.

With reference to differences in time of onset of closure in different regions of the gut, Payne and March (1962a) claimed that the proximal portion of the small intestine became closed to the uptake of macromolecules before the distal portion when the latter was protected from contact with colostrum by the presence of a ligature and that it takes 24-36 hours for the wave of closure to pass down the intestine. They also reported that when globulin was injected into the peritoneal cavity so as to produce high blood levels, there was no increase in absorption and so they proposed that the intestinal absorptive cells must be exposed to a soluble protein from the direction of the microvilli and not from the direction of the capillary bed. Bourne (1969c) agreed that the intestinal cells must be exposed to protein from the luminal side; the circulating level of immunoglobulin has no effect.

The claims of earlier workers that the proximal part of the small intestine closes before the distal portion have been investigated by Leary and Lecce (1976). They found that each part of the intestine has its own inherent capacity to absorb macromolecules, so that when a portion of the ileum was surgically transposed to the proximal intestine, the transposed portion continued to absorb long after the proximal intestine had stopped. They claimed that by the time of birth, enterocytes in the intestinal epithelium are already differentiated with regard to their capacity for absorption and that ileal enterocytes either have more pinocytotic sites or a greater capacity for regenerating these sites than do duodenal enterocytes.

ii. Effect of corticosteroids on gut closure

There are several reports in the literature about an effect of corticosteroid hormones on gut closure. The phenomenom was first noticed by Halliday in 1958 and 1959, when he observed that administration of corticosteroids induced precocious cessation of antibody absorption in suckling rats and mice. Administration of the corticosteroids also produced a rise in the level of alkaline phosphatase activity which Moog (1953) had previously shown coincided with a loss in absorptive ability. In a later paper (Halliday, 1965) he proposed that a premature cessation of absorption may be induced as a result of stressing the dam. He quoted the case of normal lambs which are able to absorb globulins during the first 48 hours of life only, so that any premature loss of this ability would have to be initiated in utero. Following studies on hill lambs, he stated that many of them obtain milk during this period but fail to absorb any

immunoglobulin, possibly as a result of their dams being under stress immediately prior to and during parturition.

In a similar vein, Kruse and Buus (1972) reported considerable evidence for the involvement of corticosteroids in the termination of intestinal absorption of immunoglobulins in suckling rats and they carried out investigations to see if a similar mechanism operated in calves. They found that cortiosteroid levels are much higher in the newborn calf than in the foetus and that calves born per vaginam had higher levels than those born by caesarian section. As a result of their findings they considered that it was possible that the calf could receive a corticosteroid "shock" at parturition which could be responsible for terminating the uptake of immunoglobulins in newborn calves. By way of contrast, however, Stott (1980) claimed that cortisol levels were not elevated in calves which had undergone a difficult parturition and there was no effect on immunoglobulin absorption. He did, however, find that certain prepartum stresses on the dam (such as heat stress) could influence colostral immunoglobulin uptake by the calf.

According to Lecce (1973), the induced gut closure could be accelerated by a stressful dietary management situation such as only feeding 4 times daily and under these circumstances, the intestinal epithelium from 3 day old pigs ceased taking up macromolecules and so behaved like epithelium from 14-20 day old piglets. It has been shown (Husband, Brandon and Lascelles, 1973) that corticosteroids reduce the permeability of the cell membrane to macromolecules such as immunoglobulins and they compared the efficiency of immunoglobulin absorption in calves born to control

cows as well as calves born to cows which had been treated with corticosteroids, in the latter, absorption was only half that in the former. The relevance of such findings to a practical situation has been emphasised by Stott, Wiersma, Menefee and Radwanski (1976) who postulated that physiological stress can activate adrenal steroid output and this in turn may reduce immunoglobulin absorption during the critical 24 hour period immediately post partum and may interact with other environmental factors such as ambient temperature to determine the survival of the newborn.

6.5 Presence of factors in colostrum which aid absorption of immunoglobulins

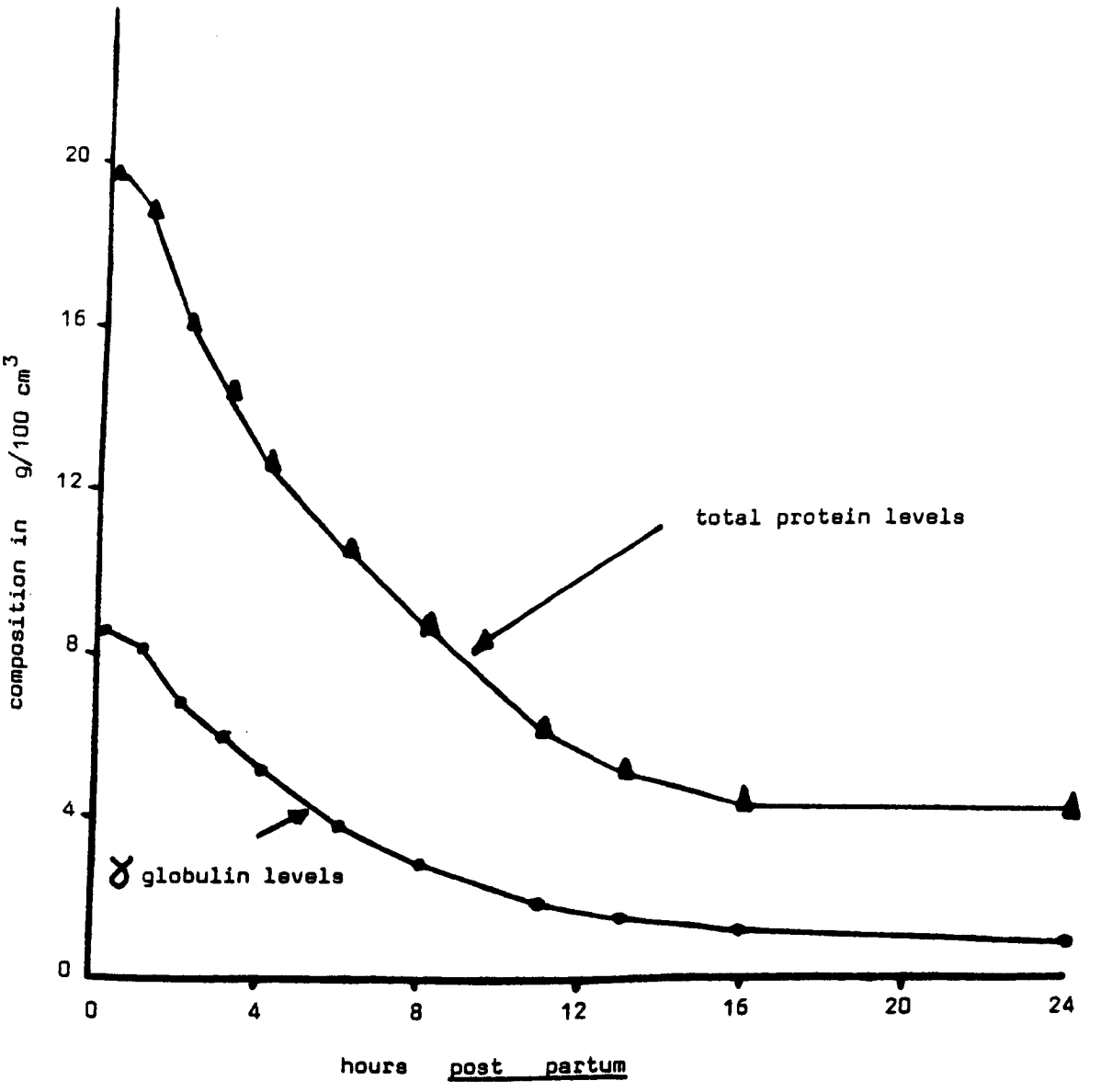
It has been claimed (Martinsson, 1970) that factors in colostrum are essential in the absorption of intact immunoglobulins for, when he fed labelled antibodies in colostrum, after 12 hours 90% of the radioactivity was bound to plasma proteins, whereas when similar labelled antibodies were fed in saline, only 10% of the radioactivity was bound to the plasma proteins. As immunoglobulins are large protein molecules, it might be considered unusual that they are absorbed intact i.e. they escape digestion in the gut. In fact, one hypothesis concerning gut closure proposes that the cessation of protein absorption is not due so much to a decrease in absorptive capacity, as to the start of protein digestion (Bainter, 1973). If a protein is fed orally (as with colostrum) it must escape breakdown in both the stomach and small intestine in order to be absorbed intact. Gastric proteolysis is certainly limited; Morris (1968) and Kidder and Manners (1972) showed there is a low pepsin activity in the

neonatal pig stomach and that colostrum itself has a buffering action. However, Hardy (1969b, 1970), claimed that the piglet gut showed vigorous proteolytic activity even within 5 hours of birth and that this activity increases with age. He reported that in newborn pigs, the blood radioactivity levels of animals fed labelled serum γ globulin was much less than that in animals fed labelled PVP and he proposed that the low blood radioactivity levels did not denote deficient absorption of macromolecules but rather, that much of the labelled protein fed had been broken down. Likewise Barrick, Matrone and Osborne (1954) observed that when porcine γ globulin was administered orally to piglets (i.e. not present in colostrum), only a small proportion was actually absorbed into the blood. They reasoned that for a piglet to feed on colostrum and to ingest immunoglobulins only for these to be degraded in the gut was an inefficient system and they proposed that colostrum contains a component which inhibits protein digestion. The exact nature of this component was discovered by Laskowski, Kassell and Hagerty (1957) when they isolated a trypsin inhibitor from sow colostrum; its activity was greatest at farrowing and fell rapidly during the succeeding 5 days. Similarly, Hardy (1965) found that when trypsin inhibitor from bovine colostrum was administered to newborn piglets, the breakdown of colostral proteins was reduced, while sow colostrum trypsin inhibitor was even more effective.

6.6 Change in mammary secretions from colostrum to milk

A dramatic fall in colostral whey proteins within 24 hours of the birth of the first piglet has been observed by Bourne (1969a)

Fig 6.2 Change in the Composition of mammary secretions after farrowing
(based on the mean results of 9 sows from Bourne, 1969a)



(fig. 6.2); likewise Zintzen (1974) reported that total protein concentration fell from 18% to 7%, while the proportion of γ globulin in the protein fraction fell from 51% to 27% in the first 24 hours. In another experiment (Bourne, 1969b) he investigated the effect of delayed suckling on the change in mammary secretions; as each piglet was born, it was placed in a heated box in the creep area so that the sow could not suckle until parturition was completed. As a result of this, he found that there was no fall in the colostral whey proteins until suckling started and that the piglets showed less variation in serum protein levels than when they suckled naturally. In a later paper, (Bourne, 1969c) he claimed that mammary secretion approximates to milk whey rather than colostral whey about 13-16 hours from the start of parturition and the rate of fall varies little between sows irrespective of the initial protein concentration, the size of the litter or the duration of farrowing.

6.7 The importance of colostrum

From the accounts above, it would seem obvious that the ingestion of colostrum by a piglet as soon as possible after farrowing would greatly enhance its chances of survival. There are many reports in the literature confirming the beneficial effects of colostrum on growth rate and survival in pigs (e.g. Owen, Bell, Williams and Oakes, 1961; Perry, 1964; Perry and Watson, 1966, 1967b; Yaguchi, Murata, Kagota and Namioka, 1980) while Hoerlein (1957) described the necessity for ingestion of colostrum in order to synthesise antibodies and Segre (1966) claimed that without colostrum, piglets remain hypogammaglobulinaemic for several weeks and are also relatively immunologically incompetent.

Wilson (1972) described an experiment in which 1 day old piglets (which had previously been given $35cm^3$ of sow colostrum) were inoculated intravenously with 10^9 E.coli and had removed those E.coli from their circulatory system within 10 minutes, whereas piglets given $35cm^3$ of boiled milk had not effectively decreased the number of circulating bacteria within 90 minutes. Since the neonate has a very limited capacity to provide a satisfactory response to an infective challenge, time is very important e.g. the generation time of enterobacteriacae may be as short as 20 minutes so that within a few hours, the alimentary canal may be populated by hundreds of millions of bacteria (Porter, 1976).

There is a strong correlation between piglets which have received γ globulin via colostrum and their ability to resist E.coli infection (Lecce and Reep, 1962). These authors stated that the presence of γ globulin is vital in the early stages of life and they proposed that it functions in 3 ways:

1) promotes localised inhibition of bacteria in gut;

2) due to absorption into the blood stream, γ globulins may inhibit any bacteria that have passed the first line of defence;

3) aids resistance by influencing the rapid maturation of the piglet's serum protein profile.

In addition, Muralidhara, Sandine, England and Elliker (1973) proposed that ingestion of colostrum may also aid early colonisation of intestinal villi by lactic acid bacteria which may possibly prevent the gut from becoming too alkaline and allowing the multiplication of bacteria such as E.coli.

6.8 Variation in the uptake of immunoglobulins between and within litters

Several workers have reported a considerable variation in the amount of immunoglobulins absorbed in different litters (e.g. Nordbring and Olsson, 1957; Bourne, 1971b) while Perry (1964) considered that there were 4 sources of this variation to which he allocated the following proportions shown in table 6.4.

Table 6.4 Factors contributing to variation in immunoglobulin uptake

Factor	Contribution
Concentration of antibody in dose	9%
Boar effects	4%
Maternal effects	39%
Individual variation in litters	48%

(Perry, 1964)

The length of suckling time needed to gain immunity is obviously important and Coalson and Lecce (1973) have shown that one hour of "suckling opportunity" is adequate for producing changes in piglet immunoglobulin profiles that are consistent with vascular immunity i.e. in one hour of suckling, piglets have absorbed substantial amounts of serum proteins from colostrum. However, the authors suggested that in order to obtain a "good hour", it is necessary to ensure that all piglets have equal access to the first colostrum and they quoted Morgan and Lecce's (1964) work which showed that the γ globulin fraction of the sow's mammary secretions drops rapidly with each ejection. Coalson and Lecce's own results showed that 15% of the piglets denied access to the

first colostrum developed a dangerously low serum immunoglobulin level and so would be unlikely to survive.

With reference to variations in antibody uptake within a litter, Bourne (1971a) found a significant negative regression of γ globulin concentration on birth order at 2 days of age, likewise Yaguchi et al (1980) reported that earlier born piglets had significantly higher γ globulin levels i.e. it would appear that the laterborn piglets are at a disadvantage as they meet with greater competition for teats and only obtain colostrum of a lower protein concentration. Bourne (1969c) suggested that the early suckling behaviour of the piglet provided the explanation to this; early born piglets usually suckle within a few minutes of birth and they do not remain on one teat but move from teat to teat, taking colostrum from each (see later). With each subsequent delivery, a let down of colostrum occurs and this, plus the disturbance created by each birth, appears to stimulate the piglet into even greater suckling activity. Bourne thought this may help to account for the very variable γ globulin levels found in naturally suckled pigs and he claimed it means that earlier born piglets may have physiological and immunological advantages over later born littermates - a situation which would be further aggravated by a prolonged parturition. He also suggested that, for practical purposes, the fostering of piglets with an immature serum profile needs to be done as soon as possible after birth. Once born, it is essential that an animal suckles as soon as possible and work with calves (Selman, 1969) showed a significant negative correlation between the time taken to achieve the first successful suckling and the immunoglobulin levels at 48 hours

post partum. There also appears to be an effect of birth weight as well as birth order on γ globulin level with Yaguchi et al (1980) reporting the existence of a significant positive correlation between the two.

6.9 Nursing behaviour of the sow

Nursing behaviour may be initiated by either the sow or the piglets according to Signoret et al (1975). The sow's normal suckling position involves lying fully extended on her side according to Fraser (1974). Sows generally lie equally on both sides but some sows lie consistently on one. This may cause a reduction in milk flow as the ventral row of teats may not receive adequate massaging; this may also be the case in those sows which stand while suckling (Fraser, 1974). Other problems may be caused by the failure of some sows to expose their ventral row of teats (English, 1969). Nursing behaviour is frequent (approximately every hour) and the sow needs considerable stimulation from the piglets before the milk is ejected (Signoret et al, 1975). During suckling, the sow gives rhythmic grunts and frequently the rate of grunting is fairly constant for a minute or more before it increases. The flow of milk normally begins 25-35 seconds after the start of rapid grunting (Signoret et al, 1975).

6.10 Suckling behaviour of the piglets

As a result of his observations, Randall (1968, 1972a) concluded that the ability of piglets to find a teat was governed by chance; they suckled at any protruberance on the sow and even when they were close to a teat, they appeared not to appreciate its presence and to suck at the surface of the adjacent gland. Once

they had suckled successfully however, they had less difficulty in regaining a teat. Randall also noted that during the farrowing period, early born piglets did not show a preference for a particular teat, but changed teats several times.

The use of indiscriminate nuzzling to find the teats has also been reported by Jones (1966b) and the fact that piglets often sucked the ventral prominence of the vulva, frequently remaining there until they were disturbed by the movement of the sow or the birth of another piglet.

English (1969) observed that in the first few hours of their life, the piglets never settled down and were always crowded around the sow, seeking the teats. Once they had had an adequate suckle, however, they became less active and lay down under the heat lamp for long periods so that they were less likely to be crushed then.

Hartsock and Graves (1976) described how the newborn piglets moved about until they encountered a vertical surface; in the natural environment this would be the sow or another littermate but in modern management systems it could be a wall or bar etc. The exploratory behaviour shown by the piglet at this stage is virtually identical regardless of the surface encountered and it lasts until the piglet grasps and suckles a teat. The authors claimed that although the eyes open soon after birth, newborn piglets do not seem to be able to visually identify teats at first and they noted that piglets exploring the udder with their snouts frequently passed within a very short distance of a teat without responding to it. They called such behaviour "teat

seeking" and claimed it was not aggressive. Once the piglet has contacted and suckled the initial teat, it then tends to move from teat to teat i.e. it shows "teat sampling" behaviour. Piglets remain orientated to the udder and keep their snouts at the correct height which facilitates teat contact.

Aggressive behaviour (such as biting or pushing with the nose or shoulder) is shown by intruders towards those piglets already suckling and the latter respond to this by positioning their body so as to make the teat inaccessible to the challenger. Such fighting is most common 2-3 hours after birth at the teat sampling stage.

Teat sampling is followed by the "teat defence" phase in which piglets confine their activities to specific areas of the udder and interactions are limited to adjacent littermates i.e. the piglets are developing preferences for particular teats; the teat order is developing (Hartsock and Graves, 1976). Following the successful defence of a given teat, the piglets settle into a routine of sleeping and suckling and relatively little fighting takes place by 6-7 hours post partum. Since the newborn piglets are very active in the first few hours of life, they tend to lose heat from muscular activity and by exposing more of their body surface so it is an advantage to the piglets to conclude the fighting stage and enter into an energetically efficient sleeping and feeding routine.

5 phases of piglet behaviour during suckling have been identified by Signoret et al (1975):

i) Piglets collect at the udder and jostle for position.

ii) They nose the udder vigorously with their snouts.

iii) They hold the teats in their mouths and suckle with slow mouth movements of about 1/second.

iv) When the milk flow begins, the piglets suddenly draw back from the udder and commence sucking with rapid mouth movements of about 3/second.

v) When the milk flow ends, they may dart from teat to teat and recommence suckling slowly or nosing the udder.

Donald (1937b) described the "snout to snout" communication between sow and piglets prior to the start of suckling and he speculated that this encouraged her to release her milk. He also identified 3 stages of suckling which he classified as i) massage of udder, ii) rapid suckling, iii) repetition of i) but with little milk produced. Mount (1968b) also observed how the piglets nose the udder vigorously at the start of suckling and how the duration of this phase increases as the piglets grow older. This stage is followed by a short quiet period in which the piglets lie down holding onto the teats, frequently with their ears drawn back. At this stage they are receiving little milk, then ejection occurs for about 20 seconds. At the end of this period the piglets detach themselves from the teats and frequently the litter falls asleep at the end of suckling.

The establishment of a specific suckling or teat order has been reported by McBride (1963), Fraser (1974), English et al (1977) and Jones-Baade (1978). Wyeth and McBride (1964) observed that

17.5% of the piglets they studied suckled 2 teats, but not to an equal extent in that the front teats were preferred. It is generally agreed that the front teats are more desirable as they produce more milk and are in a safer position away from the sow's hind legs (Stephens, 1971). The significance of the teat order is related to quiet and orderly feeding behaviour and helps to eliminate competition (McBride, 1963) for if fights break out, the 20 second milk flow may pass before these are settled and the teats adequately gripped (English et al, 1977). Since the newborn piglet has a low energy reserve, the missing of a feed can be crucial and with each successive feed that is missed, the chances of ensuring an adequate suckle next time are progressively reduced. The importance of suckling success was indicated by Hartsock and Graves (1976) who reported that piglets which survived for more than 3 weeks suckled for 79% of all the possible nursing periods whereas piglets which died suckled for only 53% of the possible feeding time. An adequate milk intake is also a pre-requisite for a rapid growth rate as the piglet normally doubles its birthweight during the first week of life; Gill and Thompson (1955) obtained a correlation of 0.98 between milk consumption and growth rate up to 19 days of age.

Several authors have reported a relationship between ingestion of milk and piglet body weight. Jones (1966b) stated that small piglets suffered in competition for teats and often went without milk for long periods while England (1974) claimed that the small pigs within a litter are at a disadvantage after the first 8 hours when milk ejection becomes intermittent rather than constant.

Heavier piglets seem to be more successful in stimulating the ejection of milk from the udder (Donald, 1937a; Hartman, Ludwick and Wilson, 1962; Walters, 1965; Hartsock and Graves, 1976).

6.11 Time taken to achieve the first successful suckle

The interval to first successful suckling ranges from 3-153 minutes, with most pigs suckling in the 10-35 minutes following birth, (Pomeroy, 1953; Jones, 1966b). Similar results have been obtained by Swedish workers (Andreasson and Svendsen, 1979) who reported that 49% of the piglets had suckled within 20 minutes and another 21% within 40 minutes of birth. It has been observed (Jones, 1966b) that in pigs which took a long time to reach the udder, it was usually their own inability to find the teats that caused the delay, but occasionally it was an intact umbilical cord that was the limiting factor. By way of contrast, Andreasson and Svendsen claimed that 76% of piglets born with intact cords had suckled by 20 minutes and of these, only 4% had died in the next 72 hours, which emphasises the advantage of rapid suckling.

According to Gill and Thompson (1955), the pig is the quickest of all the domestic animals to start suckling, and it may even begin before the umbilical cord breaks, while Hartsock and Graves (1976) observed that piglets start their teat seeking behaviour within moments of birth. There is a difference between the sexes in time taken to suckle with the females suckling sooner than the males (English, 1969). English also observed a significant positive relationship between birth order and suckling time i.e. the laterborn pigs took longer to suckle successfully. In addition, he reported that the longer the cord remained attached the longer the time taken to suckle. He suggested that this was possibly because energy is required to break the cord and so the longer the

cord is attached, the more energy is expended and so the piglet has less energy left to achieve a teat place and to suckle. Commercially, of course, it is desirable that piglets suckle as soon as possible in order to obtain a source of nutrients and immunoglobulins, so that they are best able to withstand the rigours of post natal life.

Chapter 7

PREWEANING PIGLET MORTALITY

7.1 Introduction

Preweaning mortality includes the loss of whole litters (which is relatively rare) as well as the commercially more significant losses of 1 or 2 pigs per litter. The reduction of preweaning mortality would enable significant financial gains to be made as most of the costs of weaner production are fixed and are therefore independent of litter size, so that the more weaners produced, the lower the overhead cost of producing each pig (English, 1969).

Human infant and piglet mortality rates have been compared by Arbuckle (1967); in 1958 the infant mortality rate to 4 weeks was 3.8% whereas the piglet mortality rate to weaning (usually 8 weeks) was approximately 25% but he claimed that the bulk of this had occurred by the end of week 4. He concluded that the piglet mortality rate was 5½ times greater and was static whereas the infant mortality rate was falling steadily. A more recent estimate of preweaning mortality in Europe was given by Bjorklund (1981 loc.cit) who claimed a figure of 20%.

7.2 Estimates of preweaning mortality

There are numerous estimates of preweaning mortality to be found in the literature but many of them lack details of age at weaning and whether the mortality refers only to liveborn pigs (table 7.1). Despite these deficiencies however, there is a general consensus that between 20-25% of all pigs die between

birth and weaning. The bulk of this mortality occurs in the first days following birth (table 7.2) and a large proportion on day 1; estimates of 28% by English *et al* (1977), 26% by Hutchinson, Terrill, Morrile, Norton, Meade, Jensen and Becker (1954) and 15.3% by Fahmy and Bernard (1971) have been reported.

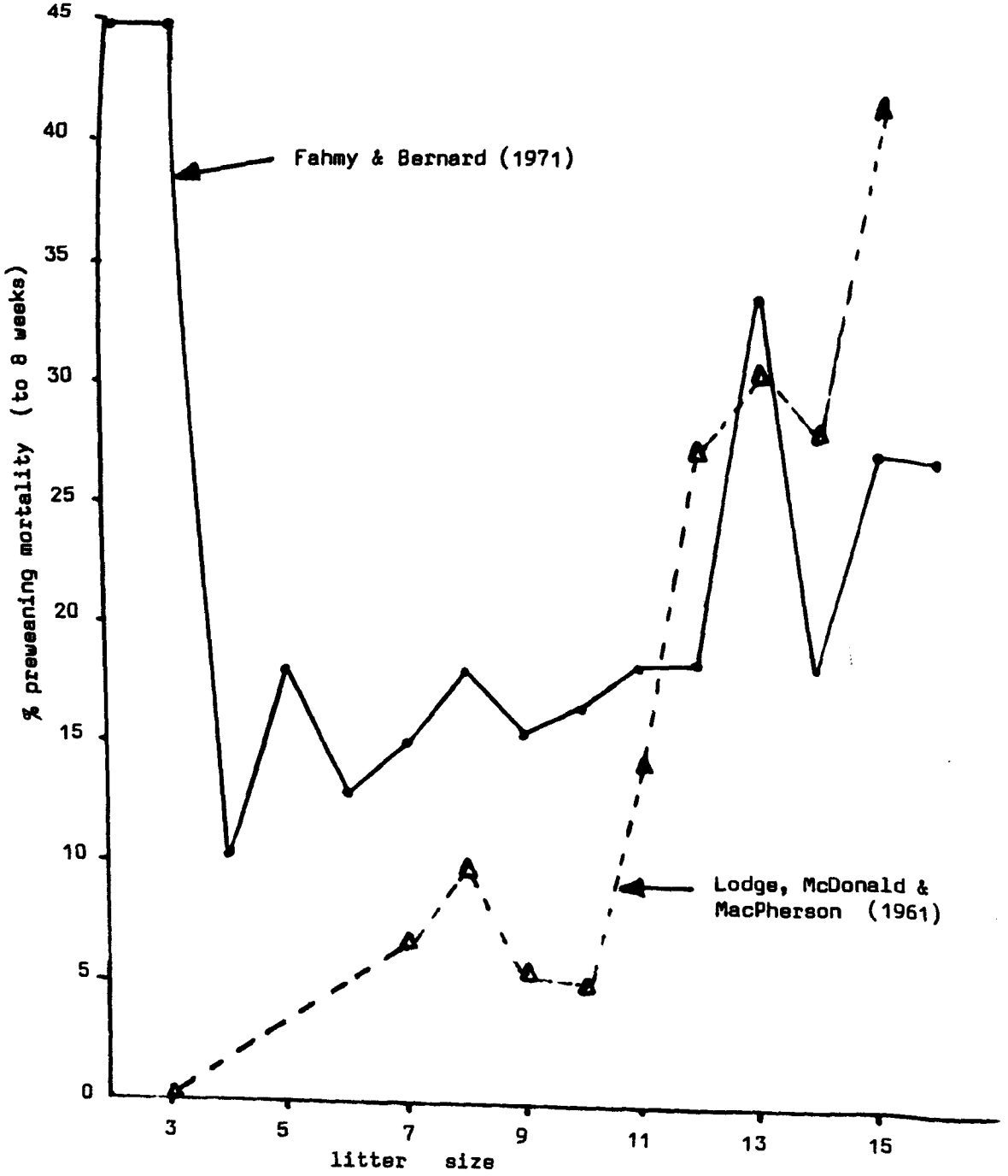
Table 7.1 Estimates of preweaning mortality

Author	Year	Period	% mortality
Aumaitre *et al*	1975	Preweaning	19.8
Bauman *et al*	1966	Birth → 6 weeks	13.0
Belic & Soldatovic	1965	Birth → 4 weeks	17.9–23.0
Bille *et al*	1974b)	Preweaning	18.3
Bille *et al*	1976	Preweaning	22.5
Braude *et al*	1954	Birth → 8 weeks	29.5
Cody	1966	Birth → 8 weeks	22.7
Gracey	1955	Preweaning	18.2
Hutchinson *et al*	1954	Preweaning	31.0
Kernkamp	1965	Birth → 8 weeks	20.5
Leman *et al*	1972	Preweaning	>25
Longwill	1951	Preweaning	22.0
Maksimovic	1976	Birth → 8 weeks	14.7
Ministry of Agriculture	1959	Preweaning	25.9
Meat & Livestock Commission	1974	Preweaning	13.4
Pomeroy	1960a)	Preweaning	26.5
Simensen & Karlberg	1980	Preweaning	22.2(10.5–29.8)
Smith	1972	Birth → 8 weeks	24.0
Stanton & Carroll	1974	Preweaning	13–25.0
Steinbach	1971	Preweaning	22.0

Table 7.2 Timing of preweaning mortality

Author	Year	Period	% age of total preweaning mortality
Arbuckle	1967	Birth → day 7	80
Bauman *et al*	1966	Birth → day 3	66
Bille *et al*	1976	Birth → day 3	14.5
Bjorklund	1981	Birth → day 7	66
English & Smith	1975	Birth → day 2	50
English *et al*	1977	Birth → day 7	73
Fahmy & Bernard	1971	Birth → day 7	43.7
Fraser	1966	Birth → day 7	75
Hutchinson *et al*	1954	Birth → day 3	48
Kernkamp	1965	Birth → day 7	11.5
Pomeroy	1960b)	Birth → day 3	70.2

Fig 7.1 Relationship between preweaning mortality and litter size



7.3 Factors affecting mortality

i. Litter size

The number born alive in a litter affects their survival as the mortality rate increases with increasing litter size (Gracey, 1955; English and Smith, 1975; fig 7.1). Others have reported that the mortality rate remained fairly constant for litter sizes up to 10-12, but then increased sharply as litter sizes rose above this (Ministry of Agriculture, Fisheries and Food, 1959; Glastonbury, 1976).

ii. Sex

Although some authors have failed to show significant differences in mortality between the sexes (e.g. Pomeroy, 1960b; English, 1969), others have reported a higher mortality rate in male pigs (e.g. Meyer, 1947; Bereskin et al, 1973; Bille et al, 1974a). It has been shown that the relative weight of the liver is greater in female piglets (Lowrey, 1911) which could mean that it contains more glycogen, thus making the piglet less susceptible to anoxia (English, 1969). The latter author had observed that females suckled more quickly after birth than did the males and that this difference approached significance. This observation could mean that females were more vigorous and/or they had a better developed suckling instinct.

iii. Birth weight

All authors seem in agreement that birth weight significantly influences piglet mortality (table 7.3) while Bereskin, Shelby and Cox (1973) having analysed date from over 10,000 litters, claimed that birth weight was the most important factor determining survival. According to Pomeroy (1960b) the mean

birth weight of pigs that died before weaning was 1003.5g compared with 1258.5g for the birth weight of the survivors. A highly significant ($P<0.01$) negative correlation of - 0.59 has been obtained by England, Day and Fogg (1976) for the relationship between birth weight and survival.

Table 7.3 Relationship between birthweight and piglet mortality

Author	Year	Birthweight (g)	% preweaning mortality
English & Smith	1974	< 860	74.6
		900-1320	21.6
		>1360	11.0
Fahmy & Bernard	1971	⩽ 450	81.7
		451-680	43.7
		681-910	24.0
		911-1130	13.3
		1131-1360	8.3
		1361-1590	5.4
		⩾ 1591	2.9
Meyer et al	1976	< 700	72.4
		700-999	37.2
		1000-1199	22.9
		1200-1799	8.2
		> 1800	5.2
Sharpe	1966	< 800	82.0
		800-1199	40.0
		1200-1499	19.2
		> 1500	7.4

Hafez (1964) described how neonatal survival is linked to the stage of maturity at birth and how, since the pig is an example of an immature species, survival depends on high birthweight. In a study carried out by Bjorklund and Svendsen (1980), there was a relationship between stillborn and weak pigs and the

incidence of lung and liver abnormalities, the incidence being higher in such pigs. The authors claimed their findings indicated an arrested or disturbed foetal development which would greatly increase the likelihood of perinatal death. The high moisture content of piglets at birth is due to a high content of extracellular water and heavier pigs have a higher moisture content which gives them an improved ability to withstand natural postnatal dehydration (Curtis, Rogler and Martin, 1969). According to Zintzen (1974), the energy reserves in a newborn pig consist mainly of carbohydrate, 80% of which is glycogen present in heart, liver and muscles which accumulates in the last 20 days of gestation. Fat deposits form only 1% of body weight and so the pig has to rely on glycogen, which means that the larger it is, the greater the glycogen store and the better its chance of survival.

The most important innate trait affecting postnatal survival is piglet vigour and this depends on i) genotype and ii) birthweight according to England (1974). He described how small piglets within a litter are at a particular disadvantage after the first 8 hours post partum when the ejection of milk is intermittent rather than constant. He also noted that since the heritability of birth weight is very low, any improvement would have to be by higher standards of management rather than an attempt to select for higher weights. It is likely that the factor of competition between members of a litter is very important as although an undersized piglet is always disadvantaged, this is particularly true if the other members of the litter are large pigs. Thus,

uniformity rather than birthweight *per se* would be the most important criterion governing survival rates. This proposal is supported by the data of English and Smith (1975) who showed that the lowest preweaning mortality occurred in litters which had a high average birthweight and only a small variation in birthweight. However, the mortality in litters with a high average birthweight but having a great variation in birthweight was as high as in the low birthweight group i.e. the authors claimed that there was no real advantage of a high birthweight for some individuals within the litter, rather uniformity of birthweight was more desirable. It seems likely though that there is a critical birthweight below which survival is unlikely e.g. the zero survival rate recorded by Day *et al* (1976) for piglets having a birthweight of less than 455g.

iv. Birth order

There is a relationship between birth order and birthweight which affects mortality in that the first born piglets are likely to be heavier and so have a greater chance of survival; for example Siers, Brown, Dekay, Mersmann and Stanton (1978) reported mortality to 14 days *post partum* as 9% for the first third of the birth order but 20% and 12% for the middle and final thirds respectively. Other workers with similar results include Arganosa and Penalba (1971), Dinu, Alexandru and Ilioiu (1978), Harmon, Totsch, Sprecher and Dzuik (1972), Hartsock and Graves (1976).

It is possible that the earlier born pigs are stressed less during farrowing and that the less viable, laterborn piglets are more concerned about breathing than feeding, which results in less

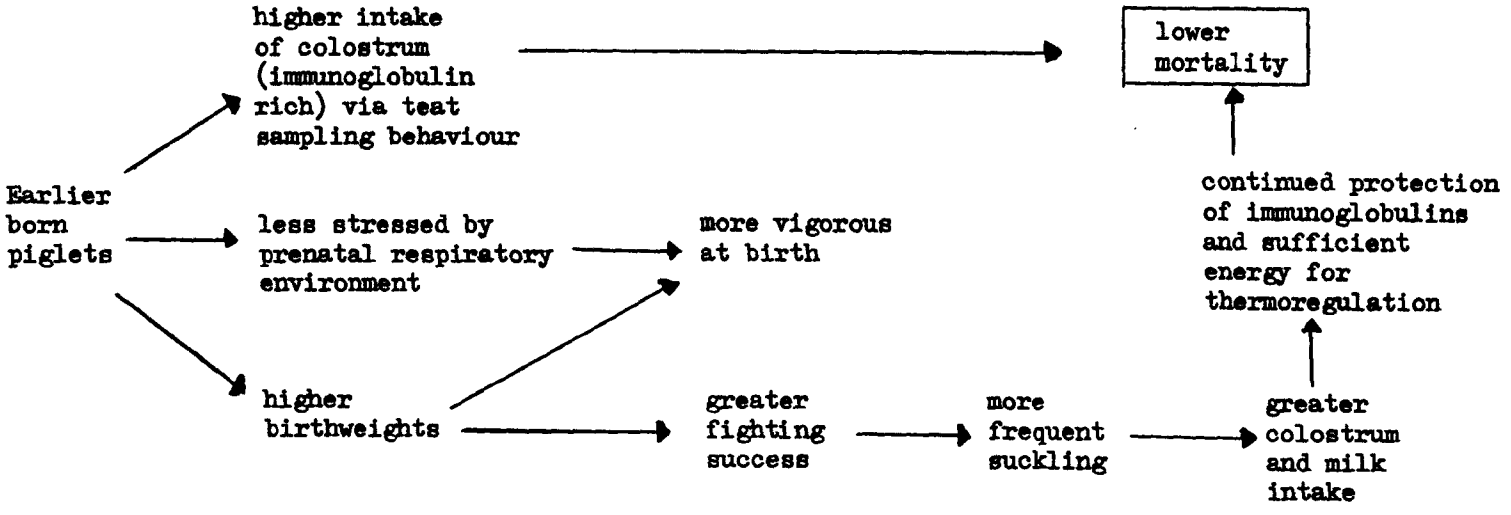
fighting success and a reduced consumption of milk (Kelley, 1977). However, the first born pigs are more subject to injury or death by crushing as the sow tends to be very restless at the start of farrowing but settles down later (English, 1969). On the other hand, laterborn pigs are more liable to prenatal injury, hypoxia at birth, enclosure within membranes at birth and are less liable to attain a desirable teat and so will obtain and absorb less adequate amounts of colostrum. It has also been claimed (Bourne, 1969c) that laterborn pigs will meet with greater teat competition and will only be able to obtain colostrum of a lower protein concentration than those born earlier.

As a result of their observations on 44 litters, Hartsock and Graves (1976) found that birth order and mortality show a significant positive correlation and they expressed the relationships between the various factors involved in mortality by means of a diagram - fig. 7.2.

v. Sow age and weight.

It has been reported that preweaning mortality increases from the second parity onwards (Gracey, 1955; Sharpe, 1966) although in his survey of Danish farms over a 10 year period, Rasbech (1969) observed a high level of mortality in gilt litters which decreased in the first sow litter before rising again in subsequent parities (table 7.4).

Fig. 7.2 Effect of birth order on mortality



(from Hartsock and Graves, 1976)

Table 7.4 Effect of sow age on preweaning mortality

Parity	No. pigs born alive	% preweaning mortality (to 56 days)	
1	8.7	16	
2	9.6	12	
3	10.8	15	
4	11.4	18	
5	11.3	18	
6	11.3	21	(from
7	11.1	21	Rasbech, 1969)
8	10.8	21	
9	11.2	24	
10	10.2	19	

With reference to sow weight, it would seem obvious that overweight sows are more awkward in their movements and so would be more likely to crush their litter; this has been shown to be true by Zintzen (1974).

vi. Duration of farrowing

There appears to be no marked effect of total farrowing time on piglet viability in those litters in which farrowing is of long duration but otherwise is proceeding normally. This was the conclusion of England et al (1976) who analysed data on piglet mortality from litters which had been born in less than 125 minutes (16.5% mortality) and from litters in which the farrowing had lasted more than 150 minutes (19.8% mortality). As duration of farrowing may be dependent on litter size, they also analysed the mortality rates of 1113 pigs with a short birth interval (mean of 4 minutes) and 109 pigs with a long birth interval (mean of 61 minutes). The survival rate at 35 days was 83.1% and 78.9% respectively and the mean weights of survivors were 7854g and 7718g for each group; thus they concluded that there is little effect of birth

interval on mortality.

vii. Type of farrowing accommodation

As indicated in table 7.5, several authors have reported considerable effects on mortality due to the type of farrowing accommodation although others (e.g. Fahmy and Bernard, 1971) have not been able to show this.

Table 7.5. Relationship between farrowing accommodation and postnatal mortality

Author	Year	Type of System	% mortality to weaning	
Bille, Nielsen, Larsen, Svendsen	1974	Tethered or in small boxes	13.8	
		Loose housed	12.0	
Blendl	1970	Crate	10.4	
		Pen	1.8	
Devilat et al	1971	Crate	10.2	
		Pen	13.5	
Lightfoot	1974	Farrowing & rearing pen	14.9	to 3 weeks
		Crate	10.0	
Ministry of Agriculture	1973	Farrowing & rearing pen	16.0	to 3 weeks
		Crate	11.0	
Meat & Livestock Commission	1973	Pens without rails	16.8	
		Pens with rails	14.6	

Most of the preweaning mortality associated with a particular farrowing system is due to trauma (i.e. crushing/overlying of the piglets by the sow) as is shown in table 7.6.

Generally, it seems that keeping farrowing sows in crates does tend to reduce mortality due to trauma although, as Maclean (1972) showed, the dimensions of the crate are critical and

Table 7.6 Mortality due to trauma as affected by farrowing accommodation

Author	Year	Type of System	Mortality rate
Backstrom	1973	Area > 5m²: Crate	3.4%
		Area > 5m²: Pen + adequate protection	5.9%
		Area > 5m²: Pen + inadequate "	7.0%
		Area > 5m²: Pen + no protection	10.6%
		Area < 5m²: Crate	3.3%
		Area < 5m²: Pen + adequate protection	6.6%
		Area < 5m²: Pen + inadequate "	10.6%
		Area < 5m²: Pen + no protection	11.4%
Baxter	1971	Crates	46% of total preweaning mort.
Bille, Nielsen & Svendsen	1974	Attended farrowing: Temporary crate in pen	2.2%
		Attended farrowing: Pen	4.3%
		Non-attend farrowing: Crate	5.5%
		Non-attend farrowing: Pen	8.4%
Fagan	1960	Farrowing stalls	2.3%
		Pens	14.8%
		Pens and creeps	17.1%
Jones et al	1966	Pens	1.4 pigs/litter
		Crates	0.4 pigs/litter
Landsudvalget	1981	Free sows (6.8m²)	3.4%
		Confined sows (3.1m²)	2.2%
Maclean	1972	Crate 76–84 x 193–244 cm	2.6%
		Crate 91 x 236 cm	20.4%
		Tether 61 x 152 cm	10.0%
		Solari pen 152 x 787 cm	6.1%
		Hut 206 x 66 cm	7.0%

crushing of the piglets by a crated sow is still the most important single cause of death (Baxter, 1971). Backstrom (1973) considered that crates are only beneficial when sows are confined for a relatively short period before, during and after farrowing as when they are confined for longer periods, the piglets have a higher mortality rate. Lower preweaning mortality rates were found in individually housed farrowing sows (11.3%) compared to group housed animals (17.3%) by Blendl (1974) and he attributed this to the sows having a more regular rhythm of lying in the individual housing. When he analysed the data from the individually housed sows in more detail, the preweaning mortality of litters from sows which had been kept in crates was 13% compared to 20.4% for litters from tethered sows. Robertson, Laird, Hall, Forsyth, Thomson and Walker-Love (1966) found no significant differences in mortality to 3 and 8 weeks post partum between litters where sows were keptin crates or pens, although they did record a higher mortality rate in the pens for the first few days after farrowing which they considered was due to the lower temperature in that type of housing. The 3 and 8 week litter weights were significantly higher ($P<0.01$) in the crate system. Devilat, Camps and Skoknic (1971) claimed that gilts in crates had reduced rates of crushing compared with pens, but that sows in crates had an increased rate of mortality and so they concluded that crates are of most benefit to gilts.

With reference to the effect of pen size on mortality due to trauma, there is a conflict of evidence available in the literature. Bille, Nielsen and Svendsen (1974) concluded that

size of pen did not affect the incidence of trauma whereas Arseenko and Rusanova (1977) found a significantly higher mortality rate of 31.7% in pens with a floor area of $5m^2$ compared with 8.5% in pens of floor area $1.26m^2$ plus $3.8m^2$ creep area.

In contrast, Anon (1981a) claimed that overlying is due to the reduction in the total space provided in a crate compared with more traditional systems (e.g. $3m^2$ in a crate compared with $10m^2$ in a Solari pen). The author claimed that although the sow has more freedom of movement in a larger pen, she effectively carries round the interaction or danger zone as she moves. Within the confines of a crate, a greater proportion of the total space has become the interaction zone. Backstrom (1973) certainly found higher mortality rates when the pen area was less than $5m^2$ compared with a larger pen (table 7.6). Simensen (1971) likewise attempted to relate piglet mortality to pen size and reported 19% mortality with pen sizes below $5m^2$ compared with 14% in larger pens. Mortality also decreased as pen width increased (table 7.7).

Table 7.7 Effect of farrowing pen width on piglet mortality

Pen width	% mortality
< 200 cm	17
201 - 220 cm	14
> 220 cm	11

(Simensen, 1971)

Obviously, it is not only the size of the farrowing pen or crate that is important in determining mortality, but also its design. In recent years, the size of most farrowing crates has altered little but the manufacturers claim lower rates of

crushing due to the introduction of "piglet-saver bars" or hinged farrowing cradles which force the sow to lie down onto her belly before rolling over, although if the cradles are not fitted correctly, they may actually increase mortality due to overlying (English, Dias and Bampton, 1982).

Finally, the type of bedding material used in the farrowing accommodation may also affect mortality, for Simensen and Karlberg (1980) reported lower mortality rates when straw was used, rather than sawdust and wood shavings; this may be due to the better shock-absorbing qualities of the former.

viii. Other factors influencing mortality

a) Umbilical bleeding

Several cases of umbilical bleeding leading to mortality have been described by Bjorklund N.E., (Pers. Comm. 1981). He claimed that the causes were unknown but stated that it appeared to be due to delayed constriction of the umbilical arteries rather than to be a fault in the blood clotting mechanism.

b) Infection

Infectious agents are only responsible for about 25% of the total neonatal mortality according to Holub (1971) who quoted various pieces of Czechoslovakian work.

c) Liver dysmetabolism

The liver of the piglet undergoes intense ultra-structural, morphological and biochemical changes in the transition from uterine to extra-uterine life (Bjorklund, 1981 loc.cit). He claimed that it normally matures very rapidly during the first 2 days after birth but that occasionally this maturation

process is disturbed; a common histo-pathological finding among piglets which have died soon after birth is the persistence of extra-medullary haematopoiesis, which is indicative of delayed maturity. He also referred to Bulgarian work in which degenerative changes were apparent in the livers of newborn piglets which had been reared under modern "industrial" conditions and be considered that these changes were symptomatic of dysmetabolic processes in the sow.

d) Hypoprotinaemia

Instances of hypoprotinaemia in newborn piglets due to their low plasma protein levels before suckling have been described by Anon (1968). Frequently, the protein level is so low that the osmotic pressure it produces is not sufficient to counterbalance blood pressure, so that fluid is forced out of blood vessels into the tissues. This would account for the subcutaneous oedema frequently observed by Bjorklund (loc.cit) in cases of perinatal mortality. Bjorklund proposed that it was probably due to disturbances in the osmotic pressure of the blood during the last period of foetal life and immediately post partum i.e. before the increased synthesis of serum albumins in the liver.

e) Hormone balance

Lambs which failed to breathe after having had their umbilical cords occluded, showed respiratory activity after they had been injected with oestradiol benzoate (Mellor, Mackay and Williams, 1972). Their ability to respond seemed to be related to their degree of maturity and their body weight

so that the authors suggested that the hormone balance of the neonatal lamb could be an important determinant of survival immediately after birth. This could also be true in piglets, for Bate and Hacker (1982) reported that when newborn piglets were injected with oestradiol benzoate, there was a significant reduction in the time taken to suckle between these piglets and others injected with saline which acted as controls (44.3 minutes v. 58.4 minutes). The authors pointed out that a difference in 14 minutes in suckling time may determine the fate of the newborn piglet, since Bourne (1969a) demonstrated a 50% fall in the protein level of colostrum during the first 4 hours of farrowing. As to the mechanism by which oestrogens can influence piglet viability, Bate and Hacker (1982) suggested that it was acting on a centre in the hypothalamus and so promoting hyperactivity with a consequent reduction in suckling time.

In another study (Hacker, Hazeleger, Van Poppel, Osinga, Verstegen and van der Wiel, 1979), the excretion of oestrogen by gilts during the last few days of pregnancy was related to the viability of the piglets produced (as estimated by time taken to suckle). They found that the mean suckling time for low viability litters was 96 minutes, whereas for high viability litters it was 42 minutes. The gilts which produced the low viability litters excreted less than 1800 µg of urinary oestrone per gram of urinary creatinine, whereas the gilts which produced the high viability litters excreted more than 2100 µg during the same 4 day period of gestation.

7.4 Causes of postnatal mortality

Two of the major factors involved in postnatal mortality are trauma and starvation (table 7.8).

Table 7.8 Some contributory factors in postnatal mortality

Author	Year	Estimated contribution to total mortality: Trauma	Starvation/weakness
Bauman et al	1966	50%	50%
Bille, Nielsen, Svendsen	1974	31%	
Bjorklund	1981	11%	26%
Fahmy & Bernard	1971	19%	27%
Hutchinson et al	1954	15%	42%
Leman et al	1972	31%	32%
Ministry of Agriculture	1959	Main cause	2nd Cause
Sharpe	1966	Main cause	
Sreckovic & Nikolic	1975	Main cause	

Smith (1972) studied 969 liveborn piglets of which 236 (24%) had died by 8 weeks and as a result of his study, he claimed that 82 different factors contributed towards the total piglet mortality, either singly or in combination (table 7.9).

Table 7.9 Factors contributing towards preweaning mortality

Factors	Estimated % contribution to mortality
A. Sow factors (including crushing)	30.05
B. Piglet abnormality and disability at birth relative to littermates	28.85
C. Obvious genetic and congenital abnormalities of piglets	11.70
D. Physical and environmental factors	4.10
E. Others	25.30
	100.00

(from Smith, 1972)

i. Trauma

An increase in the incidence of mortality due to trauma with increased litter size has been reported by Bille, Nielsen and Svendsen (1974) who also observed that 75% of all traumatic injuries occur within the first 3 days post partum. Surprisingly, they found that the pigs suffering trauma in the first 24 hours post partum were relatively large; 53% were heavier than 1300g and 34% were heavier than 1600g. The authors speculated that this was due to the greater tendency of such pigs to be born partly asphyxiated and therefore less viable. In a later study, Bille, Svendsen, Nielsen and Riising (1976) observed that trauma based mortality increased when the sow had insufficient time to become accustomed to the farrowing accommodation while sows with leg weakness also contribute to death of piglets due to traumatic injuries (Bjorklund, 1981 loc. cit.).

It has been observed that 30% of all the mortality due to overlaying occurs in the first 24 hours post partum and that it was significantly more frequent when the litter contained more than 14 piglets (Fraser, 1966). The tendency to inflict traumatic injuries on piglets was greater in certain sows and Fraser also noted that generally, there was a lower incidence of trauma in the first and second litters than in the third and fourth litters. He concluded that most crushings occur as a result of the sow flopping down from a standing position or occasionally, when the sow lay down from a "dog-sitting" position and he claimed that all "anti-crush" fittings in farrowing houses are essential.

ii. Starvation

The second of the major causes of mortality is loosely referred to as starvation or undernutrition but in practice, it is extremely difficult to apportion mortality solely to this as there are interactions between undernutrition, chilling and crushing. The piglet is born with a considerable amount of glycogen in its liver and this acts as the main energy store during the first few days of life, Bjorklund (loc. cit.). Jones (1977) quantified the energy reserves present at birth as being 11g/kg of fat and 23g/kg of glycogen. He stated, however, that the glycogen levels can show considerable variation and he considered that this may be of importance in the fight for survival; in fact he proposed that a good reserve of glycogen at birth is more important than a high birthweight. The gluconeogenetic capacity of the newborn piglet is very low and so this limits the supply of glucose for those animals which are exposed to any stressful situations such as cold or starvation (Bjorklund, loc.cit; Mersmann, 1974). Glycogen levels are rapidly depleted after birth according to Brooksbank (1958) and Shelley (1961), while Holub (1971) claimed that the glycogen reserves in a newborn piglet before suckling are only sufficient to meet its energy requirements for 7-8 hours. He reported, however, that the actual survival time is longer than this and suggested that the piglets adapt themselves to inanition by decreasing their metabolic rate. Bjorklund (loc.cit) agreed that starvation soon leads to hypoglycaemia and that the time needed for this condition to develop depends on the environmental temperature. Hypoglycaemic pigs show a slower heart rate and a fall in body temperature which leads progressively to a state of lethargy and

then coma (with consequent increased risks of overlying) followed by death usually within 24 hours.

The blood sugar levels of normal, healthy pigs has been quoted at 115 mg/100cm^3 while hypoglycaemic animals may only have 25 mg/100cm^3 (Sampson, Hester and Graham, 1942). Other figures are in general agreement with this, e.g. values of 100 mg/100cm^3 and 40 mg/100cm^3 respectively quoted by Anon (1968). The latter author claims that the problem is aggravated by the fact that for the first week of life, the piglet is unable to store glucose in its liver and so is entirely dependent on the glucose content of the dam's colostrum and milk, hence the need to suckle as soon as possible after birth. In addition, the newborn piglet is deficient in the number of hepatic mitochondria it possesses, which limits the use of carbohydrate as an energy substrate (Mersmann, 1974).

iii. Chilling

The postnatal thermal environment can greatly influence mortality (Dawes and Mott, 1959). These authors described how the metabolic rate of the foetus is similar to that of its dam on a unit bodyweight basis, but at birth the neonate has to increase its rate of heat production in order to adjust to its postnatal environment, as a result of its larger surface area. The colder the environment, the more heat has to be produced. Piglets are cold stressed at all temperatures below the lower critical temperature of 34°C; they improve in thermostability over the first 48 hours post partum, so these 2 days are critical ones (Curtis, 1974); in fact, the thermoregulatory mechanism is not fully developed at birth which accounts for the drop of approximately 1°C immediately post partum (Newland, McMillen and Reincke, 1952). According to Pomeroy (1953), the body

temperature will continue falling until the piglet finds its way round to the udder and commences suckling; this activity, plus the warmth of the sow's udder, causes a temporary rise in temperature. After suckling when the piglet is resting, the temperature falls again but vigorous piglets achieve a normal body temperature within 12 hours of birth.

Owing to its sparse hair coat and paucity of subcutaneous fat, the newborn piglet has to rely on peripheral vasoconstriction and behavioural mechanisms to combat cold, but it is very vulnerable to low temperatures (Mount, 1963), particularly as it has no brown fat (Bruck, 1970). In such conditions, the provision of ample dry bedding such as straw is an obvious advantage (Inglis and Robertson, 1953; Lucas, 1954) and Stephens (1971) found that moving a piglet onto a straw floor at 10°C had the same thermal effect as raising the ambient temperature to 18°C.

In conclusion, bearing in mind the interactions between temperature, starvation and crushing, it is not surprising that several authors have reported a seasonal effect on mortality (table 7.10) with maximal rates in the Winter. In contrast to these results, Cody (1966) claimed 2 peaks of mortality, one in mid-Summer as well as the more usual Winter peak, while Kernkamp (1965) reported only very slight seasonal differences.

Table 7.10 Effect of season on preweaning mortality

Author	Year	Observations
Bauman et al	1966	Autumn & Spring farrowings - mortality inversely related to house temp.
Bille et al	1972	Higher perinatal mortality Nov-Jan.
Bille et al	1974a)	Perinatal mortality: 14.6% Jan-Mar, 10.9% April-June, 13.2% July-Sept, 14.3% Oct-Dec.
Gracey	1955	Highest mortality Dec-Jan.
Holub	1971	Mortality may reach 30% in Winter but 10% in Summer.
Ministry of Agriculture	1959	Mortality to 8 weeks 24.6% July-Sept, 27.2% Oct-Dec.
Pomeroy	1960b)	Highest mortality in Winter
Sharpe	1966	Highest mortality in Winter.

Chapter 8

EFFECT OF EXERCISE (OR CONFINEMENT) ON REPRODUCTIVE PERFORMANCE

8.1 Types of sow housing

i. Dry sow housing

The move towards more intensive systems of housing dry sows has been continuing for some time as Baxter showed in his survey of 120 Scottish herds in 1971; even at this time, 30% of all sows were housed in stalls and 23% in fully enclosed pens. More recently (Baxter, 1981), he claimed that 75% of all large herds use some method of individual confinement. Wrathall (1975) was concerned about the effects which various environmental factors may have on reproductive performance and as Baxter and Robertson described in 1980, many herds using sow stalls still experience problems in achieving a satisfactory weaning to conception interval, mainly due to difficulties in detecting oestrus. These authors also claimed that keeping sows in groups may lead to a certain amount of antagonistic behaviour but that this can be minimised by establishing small groups of evenly matched animals in pens with "stimulating" environments such as straw bedding, while many commercial producers favour housing sows in groups on straw (Fonge, 1978; King, 1980). Sows can also be kept successfully under more extensive conditions outdoors; Duddy (1980) described how pregnant gilts lived in simple shelters throughout the Canadian winter and although temperatures went down as low as $-45^{\circ}C$, they

averaged 7.2 pigs born and 6.5 reared to weaning. Likewise Young, Reicken and Aherne (1977) described an experiment in which crossbred sows (which were normally kept in a heated building) were randomly allocated at the end of pregnancy (approximately day 90) to heated (10 to 15°C) or outside (-28 to + 9°C) housing; they were kept under these conditions until day 113, then they all farrowed inside. Surprisingly perhaps, there were no differences between the sows with reference to the litter sizes, birth weights or growth rates to 3 weeks.

The type of housing system chosen will also affect the labour requirement, being highest for individually housed sows on solid floors and lowest with slatted floors or bedded yards with scrape through dunging areas (Nygaard, Aulstad, Lyso, Kraggerud and Standal, 1970). More recent figures for the labour requirement under different housing systems are shown in table 8.1 and are based on 40 farrowing pens weaning at 5 weeks.

Table 8.1 Labour requirement under various types of farrowing accommodation (hr/week)

	Loose housed sows	Confined sows
Feeding	1.3	1.1
Cleaning & bedding	7.0	1.8
Other jobs	2.2	1.7
Total working hours/week	10.5	4.6

(Landsudvalget, 1981)

In conclusion, although dry sows may be kept in a range of

housing, by far the most common involves some type of confinement which allows more sows to be managed per man and would thus appear to be an obvious advantage in these times of greatly reduced economic returns.

ii. Farrowing and rearing accommodation

Any farrowing accommodation must satisfy 3 criteria according to Baxter (1981): i) a safe zone for the piglets away from the sow, ii) an interaction zone where sow and piglets come together for the purpose of suckling and iii) sufficient room for the sow to perform all her maintenance behaviours such as eating, drinking, excreting etc. The most widespread type of housing for the farrowing sow today is the farrowing crate. The move towards them was typified by Shanks (1948) who stated that farrowing pens with rails are not completely satisfactory and that a crate was more efficient. Thirty years later, Baxter (1978) agreed that the farrowing crate has helped to reduce piglet mortality due to overlying but Baxter and Robertson (1980) claimed that mortality due to trauma is still unacceptably high. Robertson (1978) recognised that some otherwise healthy pigs are killed by crushing and that newborn pigs are particularly vulnerable to being crushed against the back legs of the crate during birth, especially if the farrowing is prolonged. Robertson described the farrowing crate as a compromise - due to its construction the sow is under some restraint at a time when there is a need to minimise stress. In addition, he considered that the close confinement imposed on the sow appears to inhibit mothering ability with the result that she frequently flops down from a standing position and may easily crush unwary piglets. Crates

have advantages in that sows tend to keep cleaner and drier as they can only dung in one place and the piglets tend to follow their example whereas, in pens, some sows dung indiscriminately (Ministry of Agriculture, 1973). Whatever housing system is chosen, there appears to be some merit in allowing pigs access to straw as Fraser (1975) quoted Hojgaard-Olsen and Nielsen (1966) as claiming that piglets of sows which had access to straw during pregnancy and lactation were heavier at birth and weaning. Whether this was the result of the insulating characteristics of the straw resulting in a warmer environment and thus a greater piglet growth rate, or whether it was ingested by the sows and acted as a supplementary source of nutrients (unlikely), is not made clear. Likewise Sambraus (1975) observed from his personal experience that a lack of straw may lead to the sow savaging her piglets. He claimed that access to straw has a calming effect on the sow and helps to make her less aggressive. Certainly bedding such as straw seems to play an important role in the behavioural repertoire of sows, a point which is discussed further in the next chapter. For most producers, choice of housing system will be dictated by cost, with the cheaper dry sow housing systems tending to be the more intensive ones (table 8.2).

Table 8.2 Comparative costs of various sow housing systems (as at September, 1980)

a) Housing systems for dry sows

System	Cost/pig place (£)
Sow stalls	235-280
Tether stalls	190-225
Cubicles	310-330
Free access stalls	310-330
Kennels & Individual feeders	330-350
Loose housed in yards	450-470

b) Housing systems for farrowing sows

Crate house	500-900
Solari pen	580-600
Outdoor huts	30- 80 *

* Parry, R.A. (1980) Pers. Comm.

(from House of Commons Agric. Committee, 1981)

8.2 The effects of exercise (or confinement) on reproductive performance

There are numerous accounts in the literature of the inter-relationships between exercise/confinement at various stages and reproductive performance in a range of species but as many of these accounts fail to quantify the amount of exercise undertaken by the animals or to separate the effect of exercise from other variable factors such as group size, diet, temperature, access to roughage etc., it is often difficult to draw specific conclusions from the work. It is generally agreed, however, that close confinement of gilts can lead to problems with silent heats, a delayed onset of puberty and infantile genital tracts etc. (England and Spurr, 1969; Jensen, Yen, Gehring, Baker, Becker and Harmon, 1970) but there are also deleterious effects of close confinement on pregnant sows and gilts. Strangby and Gustafsson

(1971) claimed that close tethering of pregnant sows (especially young ones) often resulted in problems at farrowing and likewise Backstrom's (1973) survey showed that the most important farrowing ailments and total sow morbidity at farrowing were commoner in systems where the sow's freedom of movement was restricted to a minimum, than where sows had the maximum possible freedom of movement during gestation. In addition, the incidence of stillbirths was higher in herds with extensive restraint along with an increased incidence of piglet mortality which could be related to problems in foetal development and farrowing ailments of the sow such as a prolonged farrowing. Some examples of investigations into the effects of exercise or confinement on reproductive performance in pigs are shown in table 8.3. The results are somewhat variable and little information is given regarding any possible confounding effects such as temperature but allowing sows and gilts some degree of exercise has been shown to have beneficial effects in 18 out of the 25 cases quoted whereas there are very few accounts of beneficial effects of confinement upon reproductive performance and one is forced to conclude that confinement is a greater advantage to the producer than it is to the sow, although much depends on the level of management. A long term (i.e. over 3 parities) study of the effects of a confined or free environment during pregnancy and lactation has been carried out by Gravas (1982) and the experimental housing is shown in fig. 8.1 Sow reproductive performance is shown in table 8.4 and the results led him to conclude that it would be possible to achieve 0.7-1.2 more piglets/sow/year if loose housing systems were employed and that although loose housing systems were more expensive, the increased productivity would compensate for the increased costs.

Table 8.3 The effects of exercise/confinement on reproductive performance in pigs

Author & Year	Experiment	Results/Conclusions
Alker (1977)	3 groups of sows: a) exercised daily by attendant b) allowed free access to pasture c) housed indoors - no exercise	Amount and type of exercise did not significantly affect reproductive performance.
Dept. of Agric. for N. Ireland (1979)	Investigated various sow housing systems.	Group housed - individ. fed: 10.9 Individ. housed in stalls: 10.7 pigs born/litter
Bozhko (1976)	Compared growth rates of piglets from birth → 60 days when sows allowed exercise for up to 6hrs/day in a paddock or when confined indoors.	Exercised / Confined Mean piglet birth weight: 1.18 / 1.41 Winter (kg): 1.18 / 1.41 Summer: 1.18 / 1.16 Mean 60 day wt. Winter (kg): 16.6 / 14.8 Summer: 15.6 / 14.2 i.e. higher milk production in exercised sows

Table 8.3 continued

Author & Year	Experiment	Results/Conclusions
Burnside & Perkins (1964)	Compared various types of farrowing system.	Exercise is not necessary for lactating sows and complete confinement is possible.
Chernyi, Markov & Fedotov (1978)	2 groups of sows: a) allowed access to paddock for 2hr/day b) housed indoors with no exercise	No significant difference in numbers born and preweaning mortality.
Cutwright (1965)	2 groups of sows & gilts: a) kept under confined (i.e. semi-environmentally controlled) conditions b) kept under semi-confined conditions (access to dirt lots)	In gilts, significantly greater DLWG in piglets from semi-confined system. In sows, similar results but not significant. Piglet birth weight greater in semi-confined conditions. But significantly higher numbers born and surviving to 21 days in confined system.
Danilenko & Fedotov (1974)	Compared indoor tethered system with group housing system both with and without access to paddock.	More pigs born and reared in indoor system.
Fonda, Thrasher & Godke (1979)	Compared performance of sows allocated to dry lot pasture at weaning or kept in total confinement ($1.14m^2$/sow).	The farrowing rate was significantly ($P<0.01$) greater in the free sows and they also had larger litters.

Table 8.3 continued

Author & Year	Experiment	Results/Conclusions
Hajek & Jelinek (1976)	Compared various housing systems involving different amounts of exercise and group sizes.	Highest number of liveborn pigs obtained when sows group housed and exercised in a paddock.
Hale, Booram & McCormick (1981)	All sows and gilts tethered from service - weaning: a) forced to exercise (approx. 0.48km) from day 7p.c. to 107p.c. for 15 minutes for 5 days/week b) No exercise	Results tended to favour exercised group in terms of numbers born alive, birth weight, survival to weaning, weaning weight, although differences were non-significant.
Jones, Blaylock & Moore (1976)	Compared various housing systems.	Sows kept in 1.28m^2 slatted stalls during gestation produced piglets which were consistently lighter at birth and had higher mortality rates than the other systems which allowed more exercise.
Kabanov, Zhirnov & Simolkin (1975)	2 groups of sows: a) allowed exercise in paddock for 3-4hrs/day b) kept in pens without exercise	Exercised group had better results in terms of conception rate, litter size and piglet weaning weight.
Kalich (1975)	Investigated various sow housing systems.	Sows which had access to paddocks farrowed more pigs than those which had no access (10.3 v. 9.8).

Table 8.3 continued

Author & Year	Experiment	Results/Conclusions
Kaspar & Vejnor (1981)	4 groups of sows: a) continually tethered b) housed in boxes c) housed in boxes to farrowing then tethered during lactation d) housed in pens	a) b) c) d) Litter size at birth 9.4 9.9 9.1 9.7 % preweaning mortality 15.3 16.3 15.4 12.4
Knyazev, Simolkin & Moshkutelo (1974)	Investigated effects of various group sizes and different amounts of exercise available to sows.	No effects of treatment on litter size, birth weight or milk production.
Krutyporokh & Klochan (1973)	Compared various housing systems	Beneficial effect of systems allowing exercise in terms of litter size and growth and survival of piglets.
Krutyporokh & Zaruba (1968)	Compared various housing systems.	Beneficial effect of systems allowing exercise in terms of higher birth weight but smaller litter size and higher pre-weaning mortality.
Laird & Walker-Love (1972)	Compared performance of sows kept in stalls with others kept in groups of 4 in outside yards from 1st service as gilt to day 110 when all moved to farrowing crates.	1st parity: Stall / Yard; Mean of 2-3rd parity: Stall / Yard No. born alive 8.8 8.6 10.6 9.6 No. alive at 3 wks 7.6 7.1 9.3 8.4

Table 8.3 continued

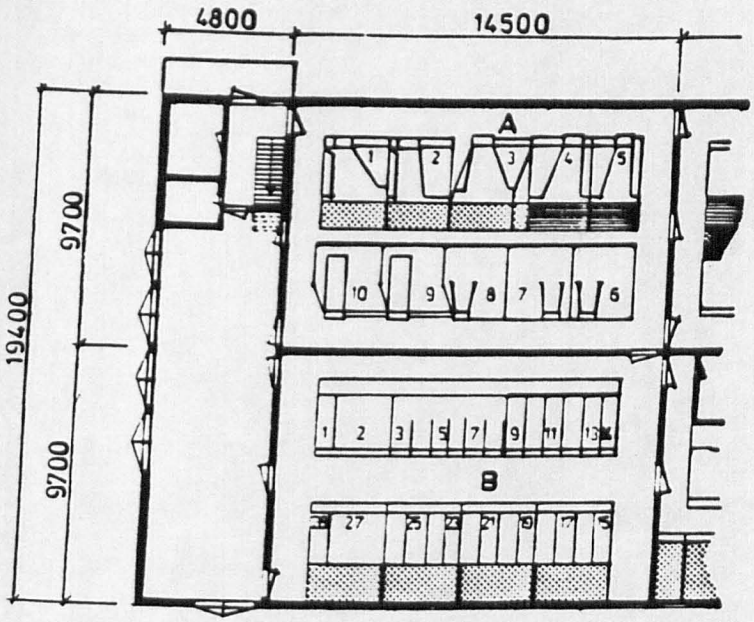
Author & Year	Experiment	Results/Conclusions
Lubenets (1976)	Compared effect of increasing size of farrowing pen from $4.0m^2$ to $7.5m^2$.	Pen size: $4.0m^2$ vs $7.5m^2$ Piglet wt at 30 days: 6kg vs 7.5kg Piglet wt at 60 days: 13kg vs 17.3kg
Mozhaev (1980)	Investigated effect of exercising gilts on pasture for 1hr/day.	Exercise provided benefits in terms of larger litters, higher milk production and greater piglet weight at 2 weeks.
Polyakov & Obenko (1978)	Compared performance of gilts which had been exercised in various ways with others which had not.	Beneficial effect of exercise on preweaning mortality.
Polyanichko & Zagorulko (1975)	Compared various housing systems offering different degrees of exercise.	Highest conception rates and litter sizes were obtained in systems which allowed gilts to roam and graze alfalfa pastures for considerable periods, as opposed to systems in which they were continually housed.

Table 8.3 continued

Author & Year	Experiment	Results/Conclusions
Strangby & Gustafsson (1971)	Compared various sow housing systems.	Tethered: No. live pigs born 11.0; No. stillborn pigs 1.5; Piglet wt at 7 weeks 9.5kg Loose housed: No. live pigs born 10.6; No. stillborn pigs 0.5; Piglet wt at 7 weeks 8.3kg
Teodorovic (1976)	Compared various types of sow housing: a) permanently tethered b) loose housed, farrowed in boxes c) loose housed, farrowed in farrowing house	a) / b) / c) No. liveborn 10.2 / 10.5 / 9.4 No. stillborn 0.4 / 0.8 / 0.4 % mortality to 28 days 12.4 / 11.6 / 18.6
Tomov (1974)	3 groups of sows: a) exercised for 2hrs/day b) allowed in paddock for 2hrs/day c) kept indoors with no exercise	General trend of results was to favour 2 exercise groups (a & b) in terms of conception rate, litter size and preweaning mortality.

Fig. 8.1 Plan of experimental sow housing

(Gravas, 1982)



A Farrowing Compartment

A1-A5 = Free sows (3300 x 2200 mm)
A6-A10 = Confined sows (2700 x 2200 mm)
(A6-A8 = Tied sows
A9-A10 = Crated sows)

B Dry Sow Compartment

B3-B14 = Confined sows (2000 x 700 mm)
(B3-B8 = Tied sows
B9-B14 = Crated sows)
B15-B26 = Free sows (2000 + 1400 x 700 mm)

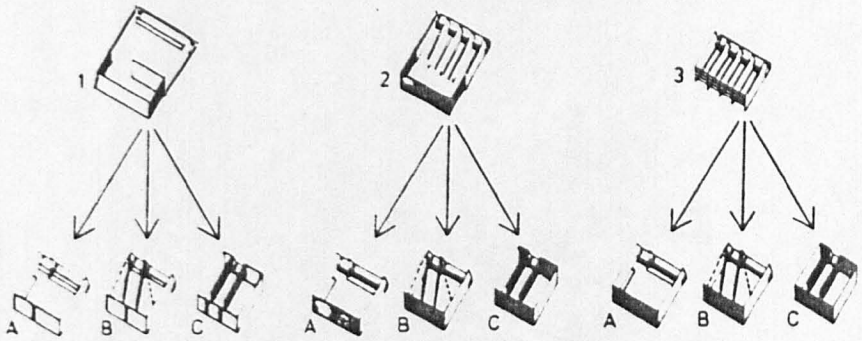
Table 8.4 Reproductive performance of loose housed and confined sows

	Experiment 1 (weaning at 6–7 weeks)		Experiment 2 (weaning at 4 weeks)	
	Loose	Confined	Loose	Confined
No. of sows	76		84	
No. piglets born/litter	10.00	9.1	9.4	9.0
No. piglets weaned/litter	8.07	7.36	7.60	7.50
Post partum mortality (%)	13.3	16.8	15.3	16.1
Empty days/sow	57.1	52.4	39.5	43.8
No. litters/sow/year	2.14	2.19	2.39	2.33
Actual productivity (pigs/year)	17.3 ($P<0.01$)	16.1	18.0 ($P<0.01$)	17.3
Potential productivity	21.4 ($P<0.01$)	19.9	22.5 ($P<0.01$)	20.9

(from Gravas, 1982)

Another large scale survey into the effects of confinement on sow reproductive performance was carried out by Gustafsson (1982) and involved 128, 643 litters. He categorised the dry and farrowing sow housing available into 6 types (fig. 8.2) and reproductive performance under these housing systems is shown in table 8.5. The results show that the stillbirth rate tends to be less if the animals are not confined, but up to 3 weeks post partum, the piglet mortality is lower in more confined systems. Much depends on the level of management, however, as the variability of results within systems was larger than that between systems and there was no information given as to the effects of confounding factors such as temperature, etc.

Fig. 8.2 Categories of Sow Housing



Type 1-3, housing of dry sows.
Type A-C, farrowing accomodation

Key a) Dry Sow Housing

1. Loose in pen.
2. Loose in pen with individual feeders.
3. Confined - individual housing.

b) Farrowing Accommodation

A. Loose in pen.
B. Confined in crate for 1-7 days post partum.
C. Confined in crate for > 7 days post partum.

(from Gustafsson, 1982)

Table 8.5 Reproductive performance of sows and gilts under different housing conditions

Housing system	No. pigs born/litter	No. pigs born alive	% stillborn pigs	No. pigs alive at 3 weeks	% mortality birth - 3 weeks
1A	11.67	11.11	4.33	9.36	14.14
1B	11.54	10.83	5.67	9.29	12.10
1C	11.50	10.88	5.03	9.21	13.60
1A-1B	*	***	***	n.s.	***
1A-1C	***	***	***	***	*
1B-1C	n.s.	n.s.	***	*	***
2A	11.64	11.10	4.10	9.41	13.90
2B	11.65	10.97	5.46	9.31	13.19
2C	11.75	11.13	4.80	9.49	12.87
2A-2B	n.s.	n.s.	***	n.s.	n.s.
2A-2C	n.s.	n.s.	n.s.	n.s.	n.s.
2B-2C	n.s.	**	***	***	n.s.
3A	11.64	11.06	4.47	9.38	13.66
3B	11.88	11.22	5.04	9.51	13.56
3C	11.72	11.03	5.35	9.33	13.59
3A-3B	***	***	***	***	n.s.
3A-3C	**	n.s.	***	n.s.	n.s.
3B-3C	***	***	***	***	n.s.

* represents $P < 0.05$
** " $P < 0.01$
*** " $P < 0.001$

(from Gustafsson, 1982)

8.3 Effect of confinement on culling rate

It might be expected that to impose such an artificial environment on a sow as complete confinement would lead to a multitude of adverse effects which would manifest themselves as a higher culling rate. Some workers have certainly claimed this e.g. Sommer (1979) (table 8.6) while Smith and Robertson (1971) described the high culling rate in 4 herds in which pregnant sows were confined to part slatted stalls and Penny (1980) remarked on the high culling rate due to lameness and paralysis which is sometimes seen in gilts that are confined during pregnancy.

Table 8.6 Culling rates of sows under different housing systems

	Group housed	Individually housed
Culled for leg defects (%)	11.2	37.5
Culled for infertility (%)	33.3	50.0

(from Sommer, 1979)

The situation is rather more complex than this, however, as Tuinte (1977) showed when he compared the performance of sows kept in groups with access to pasture with other individually housed sows which had little opportunity for exercise. The culling rate of these latter animals was twice as high as the former, with infertility being the main reason. When the second group were group housed from weaning to mating and were provided with green fodder (although they still had very limited opportunities for exercise), the culling rates in the 2 groups were similar. This suggests that, once again, there is an interaction of various management factors and it is very difficult to isolate the effects of exercise alone.

In contrast to the results above, Svendsen, Nielsen, Bille and Riising (1975) found a higher culling rate in sows kept in pens as opposed to stalls or tethers. They were unable to suggest a reason for this but claimed that their results indicated that the health status of confined sows is not influenced to the extent that culling rate has to be increased while Gustafsson's (1982) survey showed a slightly lower culling rate in confined housing. Other results show surprisingly little effect of housing system on culling rate except for the high incidence of infertility in group housed sows (table 8.7).

Table 8.7 Culling rates of sows under different housing systems

	Individually tethered	Tethered during lactation then group housed	Group housed
Year 1 % mortality & culling	21.9	27.5	25.0
Year 2 " "	32.5	30.0	32.5
Year 3 " "	20.6	17.5	22.5
Year 4 " "	25.0	25.0	20.0
% culled for infertility	23.8	7.5	37.5

(from Murgaski, Puhac and Petric, 1978)

8.4 Effect of exercise on reactions to stress

It has been proposed (Selye, 1961) that the conditioning caused by the moderate stress of exercise develops a cross resistance to various forms of pathogenic stress and he was able to show that animals can be made less vulnerable to experimental heart attacks if they are conditioned by physical exercise. Likewise, Bartlett (1956) showed that exercise can improve the response to stress in

rats; the stress had caused the rats to become more thermolabile (i.e. more reactive to temperature changes) but the degree of thermolability could be reduced by 3–10 minutes of daily exercise over a period of 12 days. When he reported that the body temperature of tethered sows was consistently lower than that of loose housed sows, Both (1972) quoted this as evidence that physiological functioning can be impaired by lack of movement and so it would seem quite feasible that the reverse situation (i.e. opportunity for exercise) could have a beneficial effect on the body's response to a stressful situation which is considered in more detail in chapter 10.

Chapter 9

PIG BEHAVIOUR

9.1 Introduction

Over the past 2 decades, studies of animal behaviour have become increasingly important as the debate over methods of intensive animal production has gained momentum. Knowledge of an animal's expected behaviour pattern (i.e. its ethogram) has been used to identify those environmental conditions which produce abnormal behaviour. Early work concentrated on such typical laboratory species as rodents, monkeys and dogs but these then proliferated to include farm livestock such as pigs.

Pigs have been described as being highly perceptive and approximately comparable to dogs in their level of awareness (Mount, 1968a). This author claimed that they generally dislike interference and when this characteristic is combined with their perceptive ability, it produces an animal which is inclined to be nervous. Marcuse and Moore (1944) agreed as they quoted Pavlov who stated in 1934 that "the pig is the most nervous of all animals and that all pigs are hysterical"! Marcuse and Moore described a case of "tantrum behaviour" in a pig which involved incessant roars of protest over a period of 2 weeks. They noted, however, that the animal always came willingly from its pen and that its heart rate seldom varied, no matter whether it was squealing or not. The results of Baldwin and Stephens (1973) support the theory that, in the pig, the observed emotional behaviour (particularly vocalisation) is not necessarily

correlated with physiological responses such as the release of the adrenocortical hormones. As a result of experiments using the escape avoidance conditioning technique, they concluded that the pig's behaviour (such as frequent urination and defaecation suggesting a state of anxiety) was not well correlated with plasma corticosteroid levels which would be expected to be elevated under such conditions.

In 1965 Thorpe described pigs as being extremely curious animals which show a great interest in their environment and Anon (1979b) also stated that exploratory behaviour is very strong in pigs, quoting the case of groups of fattening pigs which were given just a small amount of rye straw but continued to investigate it for 7 out of the 24 hours. Thorpe (1965) claimed the rapid establishment of a teat order after birth showed their high learning ability, as they are soon able to recognise a particular teat. He also considered that the domestic pig shows nearly all the needs, drives, abilities and intelligence of its wild ancestor and in a later paper (Thorpe, 1967) he claimed that this latter has a highly organised social life which means that their mental and behavioural organisation is on a high level. He explained that although a pig in a sty may <u>appear</u> stupid, this impression may be quite erroneous simply because man cannot comprehend the social organisation of its wild ancestor which (despite the effects of domestication) still determines the sensory abilities and level of feeling and perception in the modern animal. It is often postulated that genetic selection has provided strains

which differ greatly from the more primitive type form of the ancestral stock and it is also often suggested that these new strains may be better adapted to an intensive environment. But as Vestergaard and Bareham (1981) explained, intensive husbandry is still in its infancy and the animals involved have only had a few generations in which to make such adaptations. They also claimed that most behaviour patterns have not been exposed to selection and they quoted the case of feral fowls which show almost all the behaviour patterns of their ancestor, the Red Jungle fowl.

Anon (1980c) described the wild pig as being basically herbivorous, spending most of its time looking for food and eating it. He considered that when designing pig buildings, man should cater for this innate, exploratory behaviour and also for other instinctive behaviour patterns such as nest building. Many would disagree with this argument quoting the adaptability of domesticated species but, as mentioned above, there has been a relatively short time in which adaptation to more intensive environments could occur. Obviously the greatest demand upon the behavioural adaptability of any domestic species occurs when it is maintained under conditions of intensive husbandry in a rigidly controlled environment (Baldwin, 1969) such as is increasingly the case in pig production.

9.2 Effect of the environment on pig behaviour

Morris (1964) described how many animals (such as the pig) are opportunists i.e. they are always exploring and investigating,

always on the move. He claimed that such animals show neophilic behaviour (love of the new) and any new object is thoroughly investigated. The desire for exploration can only be satisfied by total familiarity with the environment and it seems as if the opportunist has evolved a nervous system that abhores inactivity so that if such an animal is placed in a restricted environment, it may perform a normal response to subnormal stimulation. In the absence of appropriate stimuli for certain activities, the animals may not only compensate by increasing other activities but they may also perform vacuum or overflow activities. The internal drive to perform a particular action becomes so intense that it requires only a feeble substitute of the normal stimulus to trigger it off and many of the resulting activities develop into stereotyped activities examples of which are shown in table 9.1 It has been stated (Fraser, 1980) that stereotypy is a pathological condition when it is persistently exhibited and there is no restoration of normal behaviour patterns.

Table 9.1 Modifications of behaviour pattern of sows in a barren environment.

	Behaviour pattern	
	Hypotrophic	Hypertrophic
Pregnant sows	Total activity	Restlessness
	Rooting	Sitting
	Walking	Standing
	Lying	Comfort activities such as conflict behaviour
	Defaecating	Unnatural lying position
	Exploring	Biting bars
		Vacuum chewing

Table 9.1 Cont.

	Hypotrophic	Hypertrophic
Suckling Sows	Total activity	Restlessness before farrowing
	Rooting	Lying
	Walking	Unnatural posture during elimination
	Standing	
	Nesting behaviour	
	Contact between sow and piglets	
	Defaecating	
	Exploring	

(from Buchenauer, 1981)

The environment may seriously disrupt behaviour in 3 ways, according to Duncan (1974):

i. A normal activity may be frustrated or blocked by some aspect of the physical or social environment.

ii. An "artificial" environment may lack key stimuli necessary for eliciting certain behaviour patterns.

iii. There may be a lack of general stimulation in the environment (equivalent to "boredom" in humans) or the environment may be so complex and unstable that the animal receives too much stimulation.

Baxter (1969) classified the environment of an animal into 3 main components - climatic, social and structural and the interactions between them influence the behaviour of the animal. In terms of the structural environment, housed livestock are affected by the man-made components such as floors, walls and equipment and these may result in injury and/or discomfort.

Wrathall (1975) was concerned that the widespread and continuing trend towards intensive husbandry systems means that pigs can no longer use their innate behavioural capacity to select an optimal environment and he regarded intensive systems of pig keeping as "unnatural".

Ekesbo (1973b) described how "barren" environments which provide few stimuli can cause abnormal behaviour and Fraser (1980) likewise quoted the free-ranging pig as spending 40% of the time resting, 35% exploring, 15% feeding and drinking and the remaining 10% on a variety of miscellaneous activities. He also expressed concern that modern intensive husbandry systems do not allow pigs to indulge in voluntary activities to this extent and claimed that the inadequacies of the environmental conditions are eventually revealed in anomalous behaviour. It has even been claimed that a poorly developed nursing instinct might be a result of the husbandry conditions in which the sow is kept (Bille et al 1974b); a very confined environment for example might depress the innate suckling patterns in the sow.

9.3 Behaviour of pregnant sows under different housing systems

i. Aggressive behaviour

Table 9.2 shows the results of a study by English, Baxter and Smith (1982) in which they monitored aspects of sow behaviour under various housing systems. The most frequent aggressive behaviour was found in group systems and was associated with competition for food, water and lying areas.

Table 9.2 Frequency of aggressive behaviour in sows under different housing systems

System	No. aggressive encounters/ 11 hour period
Straw yard	13.1
Kennel	8.0
Stall	0.6
Tether	1.0

(from English et al, 1982)

A large scale study of dry sow behaviour has also been carried out by Jensen (1980; 1981b). He observed that loose housed sows showed a more complex pattern of behaviour involving straw (e.g. chewing, collecting, shaking or pawing) than tethered sows or those with a stall and dunging passage system of housing. The social behaviour of the loose housed sows was also more complex than in the other 2 groups and he considered that the tethering of sows led to frustration of various behavioural patterns so that aggression could not be channelled nor dominance relationships resolved.

ii. Locomotor activity

Various workers have investigated the behaviour of sows under individual housing conditions such as stalls and tethers. In 1967, Baxter found a difference in the behaviour of sows depending on whether or not they were used to stalls; sows which were not used to the system were reluctant to enter unless there was some inducement present such as feed or bedding, and once in the stall, they continued to push against the rear gate for some time. When he introduced 5 sows into new, part slatted stalls for the first time, Baxter noted that they were all lying resting within

80 minutes of entering the stall, although for the next 11 hours they still remained restless and easily roused by unusual sounds. During their first 24 hours in the stall, the sows spent between 81-92% of the time lying resting, which is similar to the figure of 80% found by Robertson, Alliston and Bruce (1972) for sows individually housed in pens while Jensen (1981a) and Ekesbo (1981a) also observed that tethered sows were significantly less active during the day than loose housed sows, which is to be expected as free sows in a group need to establish a hierarchy and spend more time examining the pen.

Gravas (1981) carried out a long term study into the behaviour of tethered and free moving sows kept in stalls and concluded that tethering does not significantly reduce the activity levels of sows, although the tethered sows did spend 33 minutes longer each day lying down. In a later study (Gravas, 1982) he measured the amount of time dry sows spent lying by an indirect method involving the recording of floor temperature each minute and found that confined sows spent significantly more time lying whereas loose housed sows were 13% more active overall and maintained this activity level even into advanced pregnancy.

Other workers, however, have claimed that confined sows have high activity levels; for example Anon (1980b) reported the case of a farmer who had neck tether stalls fitted but who had great difficulty in using them; he reported that attempts to introduce sows into such stalls involved a "large amount of screaming and the pigs literally endeavouring to strangle themselves". The report did not state, however, whether the activity levels returned to normal once the sows became accustomed to their new

environment. Nygaard et al (1970) also reported shorter lying periods for sows in tethers compared to loose housed sows (66% and 80% of the time respectively).

One of the most detailed studies of dry sow behaviour was carried out by Jeppsson, Svendsen and Andreasson in 1980 and involved 100 sows; 50 of which were confined to stalls while the remainder were kept loose in boxes with discrete lying, dunging and feeding areas. Locomotor activity of 6 loose housed sows was monitored by video apparatus and the results (table 9.3) show considerable individual variation but a general trend towards increasing movement as pregnancy progresses.

Table 9.3 Distance walked by loose housed sows (m/sow/24 hr)

Pregnancy stage	Sow Number						Mean
	1	2	3	4	5	6	
Just weaned	205	183	211	242	274	262	230
Day 25	157	159	43	278	57		139
Day 70	424	255	153	289	98		244
							206

(from Jeppsson et al, 1980)

The loose housed sows moved around the pen and utilised all the available area, spending 54%, 10% and 36% of their time in the lying, dunging and feeding areas respectively. When compared with the confined sows the loose housed animals showed more postural changes over a 24 hour period 19.7 v 17.1 (table 9.4)

Table 9.4 Postural changes in confined and loose housed dry sows

Sow housing	Pregnancy Stage	Observation Day no.	Mean No. Postural changes/ sow/ 24 hr.
Confined	Just weaned	1	24.0
		2	18.0
	Day 25	1	19.0
		2	18.0
	Day 70	1	14.8
		2	12.3
	Day 90	1	13.8
		2	16.2
Loose housed	Just weaned	1	30.8
		2	20.3
	Day 25	1	15.4
		2	14.8
	Day 70	1	17.0
		2	19.8
	Day 90	1	18.4
		2	19.0

(from Jeppsson et al, 1980)

iii. Effect of bedding on sow behaviour

The presence or absence of bedding seems to influence sow behaviour under conditions of confinement such as in stalls and tethers. Fraser (1975) observed the behaviour of 6 tethered sows, 3 of which were bedded, 3 unbedded; he noted that the sows lay down more when straw was provided and that the unbedded sows performed a variety of stereotyped activities which were greatly reduced by the provision of loose straw which could be chewed and manipulated throughout the day. Unbedded sows were frequently seen standing or sitting motionless with their heads drooping and were considered to be in a state of drowsiness. This behaviour (which was virtually eliminated by the provision of straw) was interpreted as meaning that an unbedded floor surface

provided less incentive to lie down and so the high incidence of standing or sitting motionless may have indicated a lack of physical comfort.

Although Fraser found that most of the stereotyped activity was greatly reduced by the provision of loose straw, this did not occur when chopped straw was provided in the diet, although Whittemore (1979) reported that when chopped straw pellets were fed to tethered sows in addition to their normal feed allowance, they became cleaner, drier, less vocal and apparently more contented. Fraser's (1975) results showed that the sows were engaged in some type of behaviour involving their mouth or snout during most of their active moments - chewing and manipulating straw if available or performing various stereotyped oral activities if not.

Further examples of how the presence or absence of bedding can affect sow behaviour are given in tables 9.5 and 9.6. These show data collected by Vestergaard (1981) who reported that sows tend to "dogsit" rather than lie when no straw is present (presumably due to the less comfortable environment) but when straw is present, sows spent a considerable amount of time chewing and manipulating it. He concluded that the absence of bedding tends to aggravate the effects of close confinement i.e. it causes behavioural changes and a reduction in locomotor activity.

Table 9.5 Effect of bedding on the amount of time spent lying by sows

	Observation Period 1 (Straw present)		Observation Period 2 (No straw)	
	Group 1	Group 2	Group 1	Group 2
% total time spent lying	51	58	32	46

(Vestergaard, 1981)

Table 9.6 Influence of straw on selected behaviour patterns of tethered dry sows

Activity	Manipulating straw	Chewing straw	Bar biting	Head waving	Waving bite	Sit or stand still
No straw	0	0	19	15	12	19
Straw present	35	35	1	0	1	3
P	<0.05	<0.05	<0.05	<0.01	n.s.	n.s.

(Scores refer to mean number of minutes that each behaviour pattern occurred in a 40 minute observation period. From Vestergaard, 1981).

iv. Stereotyped behaviour

In recent years, many studies have indicated the relationship between the frequency of observed stereotyped behaviour and the type of sow housing. Sambraus, Sommer and Krausslich (1978) reported that individually housed sows showed numerous behavioural disturbances such as stereotyped chewing and they concluded that individual housing negatively influences well being.

Likewise, Ekesbo, Jensen and Hogsved (1978), and Ekesbo, Jensen and Loch (1979) observed a higher frequency of stereotyped behaviour in confined sows.

With particular reference to bar-biting, Fraser showed that it occurred in 3 distinct contexts:

a. When sows are disturbed especially before being given food and water.

b. In a 'chronic' form throughout most of the day in the absence of any special disturbance (this was the type virtually eliminated by the provision of straw).

c. Just before defaecation and urination.

Anon (1980c) described stereotyped behaviour of sows in stalls involving biting or nosing of the front rail, moving from one foot to another and spending long periods sitting or standing motionless. However Anon (1981b) stated that such behaviour is not universal and that some tethered sows appear to be perfectly comfortable and contented. The reasons behind these differences can be found in such critical environmental factors as the type of floor and level of nutrition etc., a sentiment with which the British Society of Animal Production in their evidence to Parliament agreed (House of Commons Agricultural Committee, 1981). Be this as it may, many ethologists remain convinced that the examples of stereotypy described above are indications of frustration in closely confined sows and Ekesbo (1981a) has even stated that such behaviour suggests that restrained sows are subject to more stress factors than those kept free in pens. This may partly account for the good results

in a pilot trial reported by Whittemore (1979) in which he recorded the effects of releasing sows from their tethers and allowing them to lie on sawdust in small groups. He reported that the untethered sows spent more time lying down, less time bar-biting, they kept cleaner and drier and there was also an improvement in numbers born.

9.4 Behaviour of farrowing sows under different housing systems

Observations of the prepartum behaviour of sows in farrowing stalls and pens have shown that the former were significantly more restless (i.e. sat up and stood up more often) during the 48 hours before farrowing (Hansen and Curtis, 1980). The presence or absence or straw bedding did not affect sow behaviour in terms of time spent sitting or standing. Strangby and Gustafsson (1971) noted that sows in crates spent more time lying down in the period immediately following farrowing than did free-running sows, although 2-3 weeks post partum the amount of time spent lying was similar for both groups. They also reported an increased tendency for crated sows to sit on their haunches like a dog and to lie on their udders instead of lying on their sides (table 9.7)

Table 9.7 Effect of housing on sow behaviour post partum.

Activity	% 24 hour period spent in that activity	
	Sow A (crate)	Sow B (pen)
Lying	77	64.6
Dog sitting	8	0.4
Standing/walking	15	35

(from Strangby & Gustafsson, 1971)

On the basis of their observations, Strangby and Gustafsson concluded that the best overall performance as regards piglet survival and health was achieved in pens with an area of more than $5m^2$ and in housing systems where the sows were only in crates for a short time at and after farrowing.

Baxter and Petherick (1980) observed the behaviour of crossbred sows kept individually in conventional farrowing crates or 5 x 5m deep straw bedded pens. Their results showed that in the 24-36 hour prepartum period, the sows in straw pens became very much more active, both in terms of the distance they travelled and the speed at which they moved. In the crates, although the amount of movement shown by the sow could change very little, their behaviour during this period did change considerably; they showed intense stereotyped bar gnawing and pawing accompanied by strenuous attempts to escape from the crate as well as copious frothing at the mouth and dilatation of the pupils. The authors interpreted this stereotyped behaviour as frustrated and displaced nesting behaviour and they considered it likely that nesting behaviour would be displaced rather than inhibited by restraint as it is initiated by changing levels of oestrogen and progesterone and not by environmental stimuli. They also considered that the intensity of the stereotyped behaviour (particularly the frothing and pupillary dilatation) indicated a stress reaction.

As a result of observing farrowings of free sows in pens, Gravas (1982) claimed that the sows tended to lie with their

rear end away from the dunging area while they were farrowing, so that the majority of the piglets were born into a warm and dry environment (table 9.8), unlike the situation with confined sows.

Table 9.8 Body orientation of loose housed sows during farrowing.

	Rear towards feed trough	Rear towards dunging area
No. farrowings	18	4
No. liveborn pigs	185	30
No. liveborn pigs/ litter	10.2	7.5

(from Gravas, 1982)

Gravas continued his observations of the lactating sows in pens and stalls at 21 days post partum and showed that the loose housed sows were very active between feeding times (07.00 and 14.00 hrs) whereas the confined sows spent significantly ($P<0.001$) longer lying down. He concluded that the activity pattern of the loose housed sows was more "natural".

In conclusion, although studies of the impact of the environment on sow behaviour are really only in their infancy, the data obtained so far do indicate a marked environmental effect on behaviour and such studies have been consistent in demonstrating an increasing frequency of stereotyped behaviour with increasing confinement, in both pregnant and farrowing sows. The question still remains to be answered, however, as to the effect of such stereotyped behaviour on the welfare and productivity of the sows and this will be discussed further in chapter 11.

Chapter 10

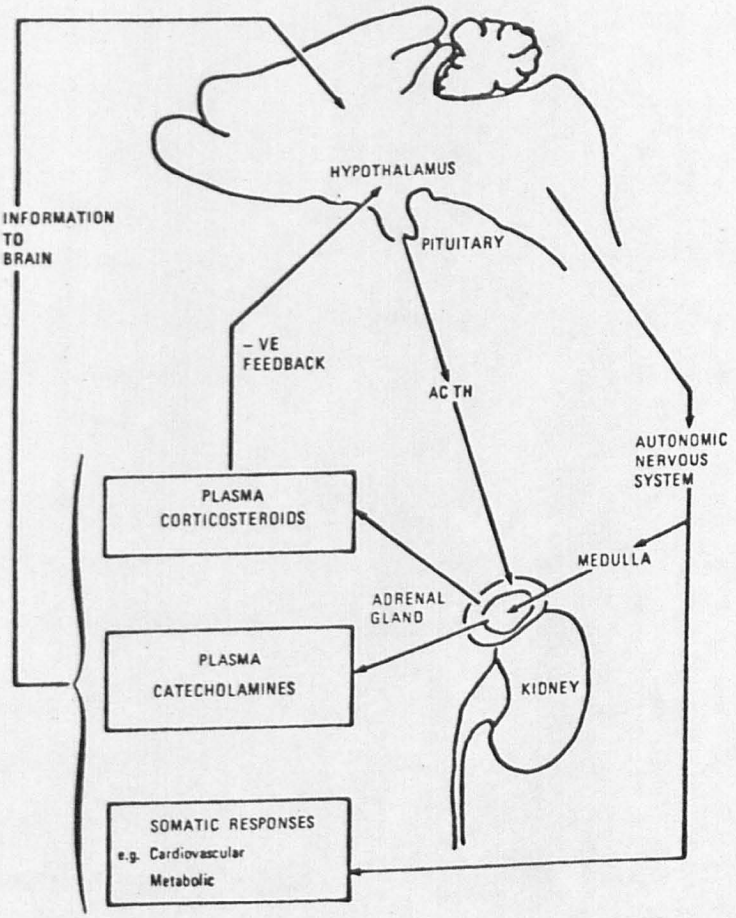
STRESS

10.1 Introduction

Perhaps Amoroso (1967) has provided the most succinct definition of stress i.e. "Situations That Release Emergency Signals necessary for Survival".

Much of the pioneering work into the effects of stress was carried out by Selye (1936) and he described how acute stressors even when applied only briefly, set a syndrome in motion which involves various biochemical, physiological and behavioural responses, some of which may continue for a long time after the termination of the stressor. In his major work on the subject (Selye, 1956), he described the reactions of animals to stress as the General Adaptation Syndrome and explained that it develops in 3 stages: i) alarm reaction ii) stage of resistance iii) stage of exhaustion. He claimed that the nervous and endocrine systems play an important part in any animal's reaction to stress, and changes in the endocrine balance within the pituitary-adrenal axis are particularly important. Initially, a stressor acts on part of the central nervous system and this then stimulates the hypothalamus to produce corticotrophin releasing hormone (C-RH). C-RH travels via the portal blood system to the anterior pituitary and stimulates the production of adrenocorticotrophic hormone (ACTH) which in turn stimulates the production of corticosteriods from the adrenal

Fig 10.1 Diagrammatic representation of events involved in General Adaptation Syndrome



(from Stephens, 1980)

gland. These are responsible for creating the metabolic changes which characterise a condition of stress; they may also have certain undesirable side effects (such as stimulating increased catabolism) and may thus be responsible for some of the adverse effects on reproduction which are apparent in stressed animals (see later). A diagrammatic representation of the General Adaptation Syndrome is given in fig. 10.1. Selye considered that if this General Adaptation Syndrome is overtaxed (e.g. by an excessive degree or duration of the stressor), the animal may face a complete and fatal collapse. Ferguson (1969) noted the reduction in non specific resistance in the later stages of the syndrome and used this as an example of the relationship between level of social stress and disease.

McDonald and Christakos (1963) were in broad agreement with Selye's hypothesis and suggested that organisms characterised by high anxiety levels experience an alarm state which involves endocrinological metabolic changes. Under these altered conditions, an animal might initially respond very effectively to a stressful situation but continuation of the stress would ultimately give rise to a reduction in the animal's ability to deal with the noxious stimulation, with the result that the body is unable to maintain its constant state of readiness to respond. The authors also proposed that the body defences are so depleted by chronic stress that it becomes more susceptible when faced with further stress.

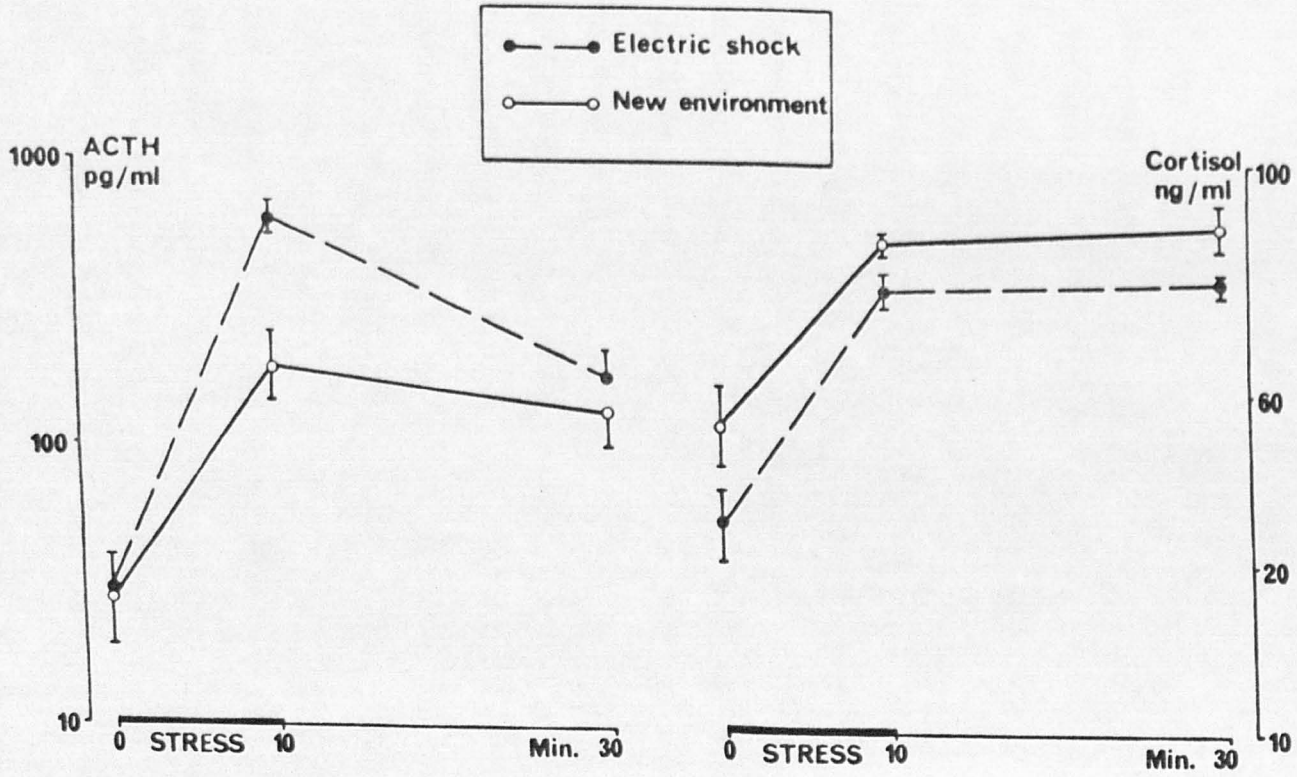
It has been proposed (Ewbank, 1973a) that stress is essentially an adaptive mechanism which helps the animal to survive and so only "overstress" is deleterious. The effects of

environmental stimuli are resisted by an animal with a complex series of interacting local and general anatomical/biochemical/physiological/behavioural responses which, in a successful adaptation, means the animal achieves homeostasis. If the stimuli have been sudden or intense in their onset, the animal may initially respond by a quick emergency reaction which is usually followed by the slower local and general responses.

The term "stress"is frequently used to cover a variety of different circumstances today although, as Duncan (1974) explained, it originally referred to a bodily state involving heightened activity of the pituitary and adrenal cortex as well as a number of related physiological features e.g. the development of gastric ulcers. The stimuli which elicited this state were called "stressors" although this term is now frequently used to describe stimuli which do not necessarily produce the classic physiological responses. In addition to Selye's General Adaptation Syndrome, Duncan also identified an emergency reaction involving mobilisation of the sympathetic nervous system.

Finally, both Fraser (1980) and Stephens (1980) have defined stress as the state when an animal is required to make abnormal or extreme adjustments in its physiology or behaviour, in order to cope with the adverse effects of its environment and management. There are many problems in attempts to assess the degree of stress in a particular environment; e.g. to a human, a particular environment may seem to be extremely restricting and

Fig. 10.2 Response of the Adrenal Cortex to Stress in Pigs



Pituitary-adrenal response of pigs to inescapable electric shocks and to a novel environment. Eight pigs were submitted to a 10 min exposure to a novel environment and, 1 week later, to a 10 min session during which 15 brief inescapable electric shocks (25 mA) were delivered. ACTH was measured by radioimmunoassay and circulating corticosteroids by a competitive protein binding method in plasma taken by puncture of the *vena cava* at time 0, 10 and 30 min. Each value is the mean of 8 determinations (Mean ± SEM).

(from Dantzer and Mormede, 1981)

monotonous, but it cannot be called stressful unless the animals show abnormal behavioural or physiological changes in adapting to it. Also, an environment may appear to be adequate and humane while actually lacking some specific stimulus which is important for the animal's normal functioning (Fraser, 1980).

10.2 Measurement of stress in animals

In their 1981 report on animal welfare, the House of Commons Agriculture Committee claimed that no single reaction can be used as a universal measurement of stress, neither did they think it possible that measurements of several reactions could be combined into a single stress index which could then be used to define unsatisfactory welfare conditions. Since a state of stress involves endocrine changes, use of this has frequently been made in the past e.g. Zuspan, Nelson and Ahlquist (1967) showed that the existence of emotional stress in human subjects led to a greatly increased urinary output of adrenalin. Likewise Frankenhauser (1971) also made use of urinary excretion rates of catecholamines in humans to try to overcome the additional stress of blood sampling. In the pig, it has been claimed that the pituitary-adrenal axis is very sensitive to short term stressors and in conscious animals, its activation reflects the psychological aspects of the stress situation, i.e. the ability of the subject to cope with that situation (Dantzer and Mormede, 1981). The response of the adrenal cortex to stress is demonstrated in figure 10.2.

In a more general approach to stress measurement, Baldwin (1981) suggested a combination of 3 physiological indices of stress:

a) endocrine changes (ACTH, GH, prolactin, cortisol etc.);

b) cardiovascular changes (blood pressure, heart rate etc.);

c) neurochemical changes (brain dopamine levels etc.).

He also emphasised that, although it may be relatively easy to detect physiological or biochemical changes in animals under acute stress, it is much more difficult to study the responses of animals which are exposed for long periods to suboptimal social or physical environments.

Owing to the difficulties involved in making physiological measurements of stress (many of the procedures themselves would act as stressors), increasing use is being made of behavioural changes (Duncan, 1974). As a result of being stressed, a new behaviour pattern may appear in an animal or else the amount of time spent performing existing behaviour patterns may change or an expected behaviour pattern may even be absent. Napier (1974) agreed that the behaviour of an animal under stress can be studied in an attempt to isolate the stressor so that the animal may then be treated. He observed that it has been claimed that, as stress cannot be measured directly, it is not a scientific term; he points out, however, that neither can schizophrenia be measured directly, but that this does not mean that the condition does not exist or cannot be treated.

The types of behavioural change which might be shown by intensively reared animals and which could indicate the first signs of stress have been discussed by Ewbank (1973b) and he listed 3 such changes in behaviour:

a) "self evident" changes which involve abnormal behaviour patterns associated with pathological changes and economic loss such as tail biting in pigs;

b) abnormal behaviour patterns which are associated with little or no pathological changes or evidence of economic loss such as bar biting in stalled sows;

c) changes in behaviour patterns which are detectable only by systematic observation such as an increase in normal agression which is needed to maintain the social order in a group of pigs.

The behavioural responses shown by animals when subjected to conditions of pain and discomfort have been listed by Thorpe (1965) as follows:

i. They struggle to escape.

ii. They contort parts of the body, especially the face.

iii. They produce sounds that are unusual in the ordinary course of life.

Other workers (e.g. Craig, 1981) have argued that it is not sufficient to rely on behavioural criteria alone to indicate the wellbeing of an animal but that physiological and productive criteria should also be used when attempting to determine the adequacy of a particular environment. Further complications arise when attempting to correlate observed emotional behaviour and physiological responses such as the release of corticosteroid hormones. Baldwin and Stephens (1973) used escape avoidance conditioning experiments with young pigs (2-4 months of age).

The pigs rapidly learnt to escape the shock but they appeared ill at ease and frequently urinated or defaecated; all activities which suggested they were in a state of stress. Their plasma corticosteroid levels, however, did not show a clear and systematic tendency to increase, especially when compared with the levels obtained after administering ACTH. As a result of their work they suggested that care needs to be taken in the interpretation of behaviour as well as in the interpretation of physiological data, for their results also demonstrated a marked diurnal rhythm in plasma corticosteroid levels with a maximum at 7.00 a.m. and a minimum at 3.00 a.m. - typical of those animals which are more active during daylight hours.

10.3 Differences between individuals in their susceptibility to stress

During the course of their experiments on rats, Sawrey, Conger and Turrell (1956) noted differences between different strains in terms of their susceptibility to stress, while Craig (1981) also claimed considerable individual variation which means that any measurement of a stress response must first establish a baseline from which to work. He quoted work carried out using poultry which showed that some genotypes withstand stress better than others and that it is thus possible to select genetically for stress resistance.

Individual variation in stress susceptibility also occurs in pigs (Dawson and Revens, 1946). These authors reported that some sows may be highly reactive to stress and this may affect their reproductive performance. A sample of 42 sows was found to vary widely in the time they took to return to their feed after having been scared off by an electrical sparking device. However, when these sows went on to farrow, no relationship

could be shown between whether they did or did not crush their piglets and the score they had achieved on the test.

10.4 Stress due to a change in the environment

A change in the immediate environment of an animal can act as a potent stressor; Holcombe (1957) described how when bulls and rams had undergone transportation and were then introduced into entirely new housing, there was an increased excretion of urinary corticosteroids which reached a maximum about 1 month after the move and disappeared after 2-3 months. Likewise McNatty and Thurley (1973) showed that when sheep were given an intravenous injection of adrenalin the increase in plasma cortisol levels was higher in those sheep which had been recently housed. After the animals had been in the new house for 2 weeks, the plasma cortisol levels decreased significantly.

In pigs, Shreeve and Thomlinson (1971) studied the effect of a change of housing on sows in conjunction with their farrowing performance and they suggested that the change of environment itself was an adverse factor with a subsequent risk of the growth of certain strains of E.coli which were already present in the gut although they were normally suppressed. Work by Dantzer and Mormede (1981) already referred to in fig. 10.2 emphasises the apparent stressful effect on pigs of being placed in a new environment; cortisol levels were even higher than when the animals had been subjected to electric shocks.

10.5 Confinement as a stressor

It has been claimed (Thorpe, 1969) that there is ample evidence available to show that confinement, just because it restricts

what is physiologically and ethologically one of the most basic and all pervading activities of animals (i.e. the locomotory response), has very powerful effects on the animal. It is known that disturbed behaviour caused either by noxious or ambivalent stimuli is greatly enhanced if the stimuli are applied when the animal is in closely confined conditions. Even in the absence of disturbing stimuli, confinement can cause gastric ulcers in the rat (Sawrey, Conger and Turrell, 1956; Sawrey and Sawrey, 1964). The way in which such restriction exerts its effects is still uncertain although Wolpe (1958) suggested that preventing escape may result in the cumulative action of stimuli which cause anxiety and that this anxiety may become associated with the surroundings in which the experiments are carried out. He also postulated that the autonomic responses may become stronger in the absence of the outlet provided by the activity of the skeletal muscles. Riegle (1973) demonstrated that restraint stress in rats produced maximal activation of the adrenocortical secretions while Kilgour and De Langen (1970) showed that individual sheep had significant differences in elevation of cortisol levels when they were immobilised. When the restraint involved tying the hind legs together for several hours, the plasma cortisol levels were greater than when the sheep had undergone dipping, being transported by truck or being chased by a dog, all of which would seem to confirm Thorpe's (1969) view that confinement or restraint is a most potent stressor. Further evidence comes from the work of Falconer and Hetzel (1964) who showed that ewes which had been restrained in cages for 3 hours showed symptoms of stress as measured by increased concentrations of protein-bound iodine while Tournut, Le Bars and Labie (1966)

reported that immobilization of finishing pigs for 24 hours produced quite severe gastric ulceration. Similarly in hens it has been shown that immobilization by hand or by crating resulted in higher plasma corticosterone levels than did 5 days of hunger or 7 days at an ambient temperature of 37°C (Beuving and Vonder, 1978).

Experiments have been carried out on rats to investigate the stress response to acute neck or body restraint (Perhach and Barry, 1970) and the results showed that plasma corticosteroid levels were highest following neck only restraint. The authors suggested that this was due to the greater freedom of the animal to struggle when the neck was the only part immobilised and they claimed that if a stressor is inescapable, the most adaptive response is a passive one such as crouching or freezing behaviour.

In contrast to this, Stephens and Toner (1975) investigated the effects of restraint stress in calves and showed that a drastic reduction in their living space (so they could not turn round in their cubicle) over a 10 day period, caused only a transient elevation in heart rate and plasma corticosteroid level in the period immediately after entering the cubicle. They concluded that such confinement does not represent an enduring and potent stimulus to the calf's pituitary-adrenal system. The authors argued that the fact that the rise in heart rate and corticosteroid levels was followed by a rapid fall to previous levels, suggested that the calves are soon

able to adapt emotionally to close confinement; there may, however, be differences between species in terms of their ability to do this.

In conclusion, although relatively little work has been carried out to investigate the stressful effect of close confinement on sows, it would seem likely in view of the evidence from other species, that intensive housing systems such as stalls, tethers and farrowing crates do act as stressors (at least initially), although it may well be that the sows are able to adapt to such conditions after a period of time.

10.6 The effects of stress on reproduction

i. General

Even the most cursory review of the literature yields many examples of the effects of stress on the reproductive process in a range of species although according to Wrathall (1975), we should be careful of the possible dangers involved in attempting to transpose observations on the reproductive processes of other animals to pigs. To quote him "... what is a stressor in one species may not be a stressor in others, particularly in the socio-behavioural field ...".

Most authors seem agreed that the effects of stress are mediated via a change in the endocrine balance. Fiennes (1974) proposed the simple hypothesis that, under stress, the pituitary produces more ACTH and fewer hormones are directed to the sex organs, so that there is a fall in both fertility and fecundity. Likewise Christian and Davis (1964) referred to an alteration in hypothalamic function under stress so that ACTH secretion is increased, while that of FSH and LH is decreased. In general

terms, prolonged stress may result in disruption or suppression of the oestrous cycle, decrease in uterine weight, failure of ovulation or implantation and this pattern applies irrespective of the stressor involved. i.e. whether it is physiological or psychological (Gray, 1971).

The literature describing how stress affects pregnancy in pigs has been reviewed by Wrathall (1975) who considered the hypothesis that stress may sometimes activate processes resembling those which occur at parturition. He pointed out, however, that at parturition it is the foetal pituitary-adrenal axis that produces corticosteroids and not the maternal one. He also speculated on the hypothesis that levels of prostaglandin may increase in stressed animals and so may partly or completely terminate production of progesterone by their lytic effect on the corpora lutea and this in turn might reduce embryo survival or even terminate the pregnancy. However, Greaves and McDonald-Gibson (1972) stated that the endogenous synthesis of prostaglandins (such as PG $F_{2\alpha}$) can be suppressed by corticosteroid treatment and so it might be supposed that in a stressed animal with high concentrations of corticosteroid, the prostaglandin levels would be lower.

To conclude, the mechanisms by which stress effects are mediated in a pregnant animal are not clear, but the actual effects themselves are not in doubt.

ii. Effects of maternal stress during pregnancy

Evidence from a range of species has been quoted by Bell (1972) to indicate that disturbances in the maternal environment

(such as psycho-social stress) can induce extensive alterations in the development and performance of the offspring.

As a result of their work with rats Shabanah, Tricomi and Suarez (1971) showed that anxiety stress applied during pregnancy can have an adverse effect on the numbers and weight of offspring. In the discussion of their work, Shabanah et al claimed that strong emotions evoke sympathetic nervous activity which causes a shunt of blood away from the splanchnic area. They stated that emotional experience includes "feelings" which are assumed to involve the cerebral cortex, while mental processes in the cortex which possess strong emotional content are also compatible with hypothalamic reactions. Due to the wide dispersion of the sympathetic fibres a generalised response follows, rather than a discrete localised effect. This response is augmented by the release of medullary adrenalin which increases the effects of impulses in the post-ganglionic fibres. The authors also claimed that under circumstances of strong emotions, the pelvic parasympathetic nerve fibres may also be activated in addition to the sympathetic fibres and this may produce an involuntary emptying of the uterus or death of the foetuses.

It might be expected that application of a stressor which leads to stimulation of sympathetic nerves would have an effect on blood flow patterns in the dam and/or the foetus. This was shown to be the case by the work of Geber (1962) in sheep, dogs and rabbits. He claimed that the dam's autonomic nervous system was involved in the maternal response and so the chemicals released by it must be the causative agents responsible for the foetal response. He proposed 2 possible mechanisms:

i) A chemical released by the autonomic nervous system passes across the placental barrier and acts directly on the foetal cardio-vascular system.

ii) The chemical acts on the placenta increasing or decreasing its blood flow and this in turn is the factor that acts on the foetus, since the supply of oxygen or removal of carbon dioxide would be affected.

With reference to the former hypothesis, it has been shown in humans that adrenalin can cross the placenta and produce significant responses in the foetus (Zuspan, Whaley, Nelson and Ahlquist, 1966). In an attempt to further clarify the situation, Crist and Hulka (1970) administered adrenalin to 2 groups of pregnant rats at different stages of gestation, while a third group acted as a control. 60% of the rats which received adrenalin during early pregnancy failed to produce offspring while the remaining 40% produced offspring that were significantly lighter. The offspring of those rats which had received adrenalin during mid-pregnancy showed significant behavioural differences when compared to the controls, in that they moved around less and were less ready to leave their home cage to reach food.

In order to explain this difference in emotionality of the offspring, the authors proposed a mechanism whereby high levels of circulating adrenalin inhibits foetal oxygen uptake via constriction of the placental blood vessels and they considered that such hypoxic conditions could produce brain damage which might lead to the observed emotional and

behavioural differences.

Other workers e.g. Piasecki, Egdahl and Jackson (1960), Dornhorst and Young (1952) have also suggested that administration of catecholamines to foetuses led to decreased oxygen uptake from the maternal blood while Windle and Becker (1943) reported histopathological changes in the brain structure of guinea pigs which had been asphyxiated during birth. This is a further piece of evidence to support the hypothesis stress → adrenalin → constriction of placental blood vessels → hypoxia → changes in brain structure and functioning in foetuses.

There have been many experiments carried out to investigate the effects of various stressors on pregnant females, but the majority of these experiments have involved rats and care needs to be taken when extrapolating these results to other species such as pigs. As a general principle, application of a stressor to a pregnant rat resulted in more emotional and less active offspring (Ader and Belfer, 1962; Hockman, 1961; Thompson, 1957; Thompson and Sontag, 1956). Rats have been used (Joffe, 1965) to investigate the effect of prenatal maternal conflict (i.e. a psychological stressor) on the emotionality and intelligence of the offspring; the results demonstrated no significant differences in terms of emotionality but the offspring of stressed mothers made significantly more mistakes when they were given an intelligence test. Joffe proposed that the stress situation produced too rapid a myelination process in the foetuses and that this explained the difference in intelligence without the accompanying differences in emotionality.

If the stressor is sufficiently severe, it may cause an alteration in maternal behaviour, for example when Huttunen (1971) administered daily electric shocks to pregnant rats, he noted that the dams ate their offspring after birth and that if 2 rats were housed together, they frequently fought. Perhaps surprisingly, the offspring of the stressed rats showed no differences from the controls in terms of growth rate and gross neurological or behavioural abnormalities. However, they showed a faster turnover of brain nor-adrenalin at approximately 40 days of age which Huttunen considered was due to a release of catecholamines or corticosteroids in the stressed dam which then crossed the placenta and entered the foetal central nervous system.

In addition to effects of prenatal psychological stressors on the behaviour of the offspring, there is evidence that a stressor such as noise can affect skeletal development in the foetus by inhibiting osteogenesis (Geber, 1973). The mechanism seems rather obscure, but Geber claimed that injections of catecholamines produce changes in the concentration of extra-cellular cyclic AMP and GMP and as catecholamines are produced in conditions of stress, this might provide a mechanism (via the cyclic nucleotide pathway) for causing an imbalance of maternal hormone levels as well as maternal and foetal Ca^{2+} levels.

Mention is made elsewhere of the fact that restraint or confinement can act as a most potent stressor, so it might be expected that this would adversely affect pregnancy. Euker and Riegle (1973) subjected rats to 2 hours of restraint stress (i.e. tied to a flat surface in a supine position) at various stages of pregnancy. The authors found that when the stress was applied before ovulation and

mating, there was no effect on litter size but mating was delayed; they thus postulated that the stressor blocked gonadotrophin release. When the stressor was applied at various stages throughout pregnancy, the effects were restricted to that time period i.e. stress applied during early pregnancy caused interference with implantation, whereas stress applied later caused reserption or abortion of the litter. Euker and Riegle suggested that the ability of the stressor to interrupt reproductive processes at several stages indicates that the mechanism of action could include alterations to gonadotrophin, luteal and/or placental secretions, or to uterine blood flow.

With reference to pigs, restraint may act as a stressor in those intensive husbandry systems where the sow is prevented from performing natural pre-farrowing tasks such as nest building (Stanton and Carroll, 1974) but the extent of such a stress is unknown.

ii. Maternal stress during delivery

Zuspan, Nelson and Ahlquist (1967) showed that in nearly all the human subjects they monitored, pregnancy itself did not act as a stressor or lead to increased secretion of adrenalin, but the process of delivery did. Zuspan et al (1966) found increased concentrations of glucose and non-esterified fatty acids in maternal blood during delivery, which they considered were the result of increased endogenous maternal catecholamine secretion.

In conclusion, although systematic studies of the effects of stress in sows are lacking, from evidence provided by other species, it would seem reasonable to conclude that i) the imposition of a very confined environment will act as a stressor (particularly in the initial stages) and ii) that the application of stressors (whether physiological or psychological) during pregnancy, is likely to have adverse effects on the foetuses, probably as the result of changes in blood flow patterns mediated by the innervation of the maternal sympathetic nervous system in addition to changes in the maternal hormone balance.

Chapter 11

WELFARE CONSIDERATIONS

11.1 Introduction

The Brambell Report (Brambell, 1965) defined welfare as being a wide term embracing both the physical and mental wellbeing of an animal; although, as Hardwick (1981) pointed out, to aim at the physical health of an animal is one thing, to try to ensure its mental wellbeing another. Welfare considerations apply to all systems of pig production although, as the British Society of Animal Production claimed in their evidence to the House of Commons Agricultural Committee on Animal Welfare (1981), extensive systems of pig production tend to be more acceptable from a welfarist viewpoint even though problems may arise due to competition for space, feed, water or shelter. As Anon (1980c) pointed out, intensive housing does not generally cater for the pig's behavioural requirements and because of this they show signs of stress at various stages in their lives. The wild pig is basically herbivorous and spends much of its time looking for food, so in the design of pig buildings account should be taken of the pig's well known exploratory behaviour and provision should also be made for the pig's instinctive behaviour patterns such as a desire to nest build prior to farrowing (Anon, 1980c). In their evidence to the House of Commons Agriculture Committee (1981), the RSPCA declared that, in the light of present knowledge, some methods of intensive pig production cause an unacceptable degree of distress

to the animals involved. They claimed that there are sound physiological and biological grounds for accepting that pigs, because of the similarity of their nervous system to that of man, experience comparable sensations such as heat, pain, stress etc. even though these sensations may vary in degree. The RSPCA felt that greater consideration needs to be given to the repressed behavioural instincts in sows particularly, as the suppression of these instincts can and does give rise to prolonged emotional disturbances. They compared the behaviour of sows rooting about in a straw yard with that of more closely confined sows, rocking backwards and forwards chewing at the bars and generally adopting abnormal postures and behaviour patterns. They claimed that the degree of suffering experienced by an animal is dependent on its own physiological and anatomical makeup, but it is also influenced, by the man-made environment in which it lives and for which man must be responsible. Intensification increases the dependence of animals on man and how well they have adapted to such conditions needs to be judged by their behavioural reactions (Kilgour,1972). The practice of individual housing, for example, may eliminate the physical effects of fighting but it may not reduce psychological stress and observation of the sows could show that they are still exhibiting signs of behavioural aberration such as bar biting (Baxter, 1974).

All the domestic animals have been described by Thorpe (1967) as having a highly organised social life and he claimed that this meant that their mental and behavioural organisation is on a high level, in fact far higher than the ordinary man imagines. He suggested

that even though a pig in a sty might appear "stupid", this impression may be quite erroneous, simply because man does not comprehend the social organisation of the wild ancestor which, despite the effects of domestication, still undoubtedly determines the sensory abilities and the level of feeling and perception in the animal. Although Thorpe may be criticised for verging on anthropomorphism with this statement, it is nevertheless a relevant point of view.

Wood-Gush, Duncan and Fraser (1975) described how, in addition to clear physiological "stress" responses, many other social and environmental conditions have been found to be aversive to animals or to give rise to abnormal behaviour without a proven physiological reaction. They considered it was likely that under modern husbandry, domestic animals (which have been kept extensively or semi-extensively for thousands of years) would be frustrated or thwarted, although Wood-Gush (1973) stated that the avoidance of all frustration in animal production is impossible and that some may even be physiologically desirable.

A consideration of animal welfare also has economic as well as humanitarian considerations, for when the basic behavioural requirements of farm animals are not recognised, their productivity can be heavily affected through injury, morbidity and mortality which is a costly business for the producer (Anon, 1979a). Wood-Gush (1973) agreed that, by and large, abuse of agricultural animals will lead to lowered economic returns, but he also claimed that there may be some malpractice present that will not appreciably affect this as the stress may have to be very prolonged for this to happen.

One of the problems when dealing with the subject of animal welfare is the difficulty of assessment and it is somewhat paradoxical that welfare is commonly assessed by evaluating its opposite (i.e. stress), simply because there is no direct physiological evidence of welfare (Dantzer and Mormede, 1981). In their evidence to the parliamentary agricultural committee (House of Commons, 1981) the British Society of Animal Production identified various methods of assessing welfare such as a study of the animal's behaviour and an assessment of its productivity. With reference to the former, they claimed that severe frustration leads to stereotyped behaviour which may cause injury to the animal and is generally unsatisfactory. Most of the work employing behavioural means of assessing welfare has been carried out with poultry, such as that described by Duncan (1981). He gave details of 3 methods which included: i) observing unusual or inappropriate behavioural changes and demonstrating that these are indicative of reduced welfare. ii) allowing the bird to choose its own environment and assuming the bird will choose in the best interests of its welfare. iii) subjecting birds to experimental stressful situations (e.g. deprivation, frustration or fright) and observing their behaviour with that which occurs under commercial conditions; considered by Duncan to be the most successful method. Measurement of productivity might be considered to be an objective measure of welfare since animals that suffer stress often do not perform as well as unstressed animals. High productivity, however, is by no means synonymous with welfare because, for example, excessive eating <u>per se</u> can become an expression of severe frustration. The best probable answer to the problem of assessing the fitness of an environment in welfare terms is the use of a combination of

methods, as suggested by Curtis, Gonyou, Grandin and McGlone (1982). These authors proposed the monitoring of the following characteristics in order to evaluate the suitability of housing systems for sows:

i) production characteristics such as longevity, number of liveborn piglets farrowed and maternal weight gain over gestation. They considered that reproductive performance in particular, acts as a sensitive indicator of stress since maintenance activities have the highest priority and so other processes are affected first.

ii) behavioural characteristics such as level of stereotypy and reactions to operational activities of the production system.

iii) physiological characteristics e.g. stress hormone concentration, circadian rhythm in metabolite levels etc.

If such a system is followed, the results are likely to be more meaningful than would be the case if one were to rely on production or physiological criteria alone.

11.2 Welfare of sows under intensive husbandry systems

With reference to intensive sow husbandry in particular, welfare considerations concern the aspects of feed level, presence or absence of bedding, lighting pattern and, perhaps most important of all - confinement, which involves both restriction of movement and isolation as well as the possibility of inflicting injury.

i. Effect of feed level

According to Anon (1981c) who quoted work by Whittemore, the high density diets which are commonly used in intensive pig units today are not providing a sufficient measure of gut fill. He claimed

that a sow's stomach can hold 25kg of root vegetables such as swedes over a 24 hour period and so feeding only about 2.5kg of a high density diet, leaves a sow feeling hungry. Perhaps as a result of this Barr (1980a) described stress problems caused by sows having to wait for several minutes for their feed. He quoted cases of prolapse and even abortion which have been attributed to extreme excitement and activity in hungry sows. In a later report (Barr, 1981) he claimed that the twisted gut condition in sows is becoming increasingly important, due to the extreme agitation shown by hungry sows waiting to be fed. Likewise, the telemetric measurement of heart rate showed that in the few minutes immediately prior to feeding, there was a greater increase in heart rate than at any other time, which suggests that this is a most stressful period (Minter, C.M., 1983. Pers. Comm.).

ii. Effect of bedding

In his evidence to the House of Commons Agriculture Committee on Animal Welfare (1981), Stolba claimed that bedding is important for all farm animals as it forms the substrate for a wide range of motivations inside the animal. These motivations are not necessarily repressed or absent just because the actual bedding behaviour is not apparent; the animal might not show rooting behaviour but nevertheless the motivation still exists. When livestock are kept outside, they have the opportunity to remove frustration by exercising other types of behaviour, but when they are kept inside, this is not possible and so the provision of bedding material may act as a safety mechanism.

iii. Effect of light

According to Stolba (loc. cit.), pigs living under natural conditions tend to sleep throughout the night, apart from short intervals when they leave the nest in order to defaecate and urinate. During the daylight hours, however, there is a great range of activities which takes place and so he concluded these pigs show a definite diurnal rhythm. If such animals are kept in continual darkness, this rhythm does not develop and the pigs fail to show any structured activities. The sense of vision in pigs is not as well developed as the senses of smell and touch, but experiments have indicated that if given a choice of conditions, pigs consistently choose light rather than dark (Walser, 1981).

iv. Effect of confinement

a) Isolation

Wood-Gush et al (1975) described how separation of an animal from its usual herd or penmates generally leads to the animal exhibiting signs of distress. For example, a suckling piglet which is removed from its mother and littermates frequently defaecates, becomes extremely active and gives a characteristic pattern of loud repeated vocalisations. The authors claimed that visual contact is important for pigs if physical contact is prevented, so tethered sows should be allowed to see each other. Walser (1981) agreed that pigs are social animals and so they need to be kept in groups with some degree of contact, even if this leads to some instances of aggression which individual housing is designed to eliminate.

b) Restriction of movement

This is probably the most obvious characteristic of intensive livestock systems, for example when dry sow stalls and farrowing crates are used together, the sows are closely confined for 10 months out of the 12 and they can only move with relative freedom in the 2 month long periods they spend with the boar each year (Anon, 1973). The advantages which are claimed for such close confinement include:

i) maintenance of an adequate winter temperature due to the high stocking density;

ii) elimination of bullying;

iii) easy observation of individual animals.

In short, it is claimed that stalls and tethers are designed to allow the stockman to look after the sow, whereas more extensive systems such as straw yards are designed to allow the sow to look after herself (House of Commons, 1981). The extremes of restriction do not seem to agree with the recommendations of the Brambell Committee (Brambell, 1965) for sufficient freedom of movement so that an animal can get up, lie down, groom normally, turn around and stretch its limbs without difficulty. The Committee agreed that confining sows (e.g. by tethering) prevents bullying, simplifies management and allows control of individual food intake but they felt unable to approve such close confinement continuously through pregnancy. To quote from the report ".... we recommend that pregnant sows should not be kept without daily exercise in quarters which do not permit them to turn around freely and in any event they should not be tethered indoors. .... it is clearly cruel to restrain an animal for a large part of its life so that it cannot use any of its normal locomotory behaviour patterns".

Sainsbury (1978) was also concerned over the long term welfare implications of providing no exercise for pigs of any age and especially breeding sows while Wood-Gush (1973) felt that the use of narrow stalls for pregnant sows may be an instance where the animal is under stress but the stress is not sufficiently prolonged for it to manifest itself as a lowered economic return. Wood-Gush et al (1975) described how prolonged restraint of sows may lead to behavioural effects. For example, when a sow is first put into a tether stall she may vocalise and struggle, but this reaction generally subsides within an hour, after which the animal may spend a large proportion of the time lying down and may develop repetitive actions such as chain or bar biting.

Other European countries are also concerned over restraining the movement of pregnant sows; in his evidence to the House of Commons Agriculture Committee (1981), Stolba described recent regulations which have been introduced in Switzerland. These state that sows cannot be kept in stalls unless they are untethered or released for at least 30 minutes per day in order to allow free movement. He also claimed that around 60% of sows in Britain are confined and are kept in stalls or tethers. In Sweden, animal welfare groups have recently proposed a ban on dry sow stalls and all types of farrowing crate (Gustafsson, 1982).

The most recent reassessment of animal welfare under modern systems of intensive husbandry was that carried out by the House of Commons Agriculture Committee (1981). In their evidence to the Committee, the Meat and Livestock Commission considered that while the main argument against the close confinement of sows is that the animal

cannot turn round and so may be the subject of mental and physical deprivation, the required physical conditions of confined sows can generally be met by good management, although they did admit that such a system is open to abuse.

Various workers have attempted to compare the welfare aspects of housing dry sows in confined or loose conditions; Daelemans (1981) concluded that behaviourally the latter was preferable as the sows had a certain amount of access to exercise in addition to having the best opportunities for keeping clean and being able to choose where they lay. Similarly, Ekesbo (1981a) was also in favour of loose housing claiming that, owing to their enforced confinement, tethered or stalled sows are forced to use the same area for their entire behavioural repertoire despite the fact that they are highly motivated to carry out different behavioural functions in different areas.

With reference to the farrowing sow, many people consider that it is necessary to restrict her movements; to quote Sainsbury (1978) ".... the sow is a clumsy mother, the worst on the farm, and some form of protective crate can be considered essential". The Brambell Committee (1965) also recognised that the farrowing sow is often closely confined in the interest of her piglets, and they did not object to the practice as long as it only covered the period of parturition and the following few days. Arising from the Brambell Committee's Report, the Codes of Recommendation for the Welfare of Livestock (1971) state that farrowing quarters should have a farrowing crate, farrowing rails or other device for the protection of the piglets and that sows should be placed in clean and comfortable

farrowing quarters well before the litter is due. The disadvantage of closely confining pregnant sows is that they may not be able to lie down normally and so may crush the piglets. Observations of the way in which sows lie down in crates have been carried out by Baxter (1981) who reported that the sow adjusts her stance and body position in ways that appear to maximise her stability. She lowers herself onto her front knees and then slides 1 knee under her body so that she is resting on 1 knee and 1 shoulder. She then increases the rotation of the front half of her body until it is in an almost recumbent position, before gently dropping her hind quarters and adjusting her posture to either sternal or lateral recumbency. In a poorly designed crate, the rotational movements of the front parts of the body are reduced so that the hind quarters drop to the ground more violently thus increasing the risk of overlying. Baxter concluded that "crate farrowing is an 'unnatural' method of animal exploitation in as much as it attempts to suppress rather than exploit the animal's own biological adaptations".

Another problem with confining farrowing sows in crates is that their hind teats can become covered in dirt and so pose a disease risk to suckling piglets and this may help to account for the high incidence of gastro-intestinal infections in young piglets in many intensive units (Anon, 1979a). Certainly a study of the degree of cleanliness attained by dry sows under different housing conditions (Ekesbo, 1981a) has indicated that when bedding is scarce, closely confined sows are considerably dirtier than free moving animals.

c) Physical injury

In his evidence to the House of Commons Agriculture Committee on Animal Welfare (1981), Sainsbury claimed that the sow is a large, clumsy animal and that she can frequently suffer injuries on the feet and body when she is closely confined, particularly if no bedding is used. Hansen and Curtis (1980) agreed and described the infliction of injury during vigorous nesting activity, while Baxter (1967) and Saunders (1972) described injuries to sows in partly slatted stalls which occurred mainly on the sow's legs and tail head due to constantly pressing against the rear gates. Laird and Beaton (1969) reported various injuries in stalled and tethered sows, including injuries suffered as a result of trying to turn around while Backstrom (1973) quoted figures which showed a considerably higher incidence of injury in crated sows compared with free-running animals (table 11.1).

Table 11.1 Traumatic injuries in sows due to confinement

During gestation		
Type of confinement	No. of sows recorded	Incidence of traumatic injury
Running free in pen	2464	0.8%
Confined in individual pens (1.8–2.0m long and 0.6–0.7m wide)	1678	6.1%
Tethered only or in combination with farrowing bow	1079	33.1%
At farrowing		
Tethered in farrowing crate (farrowing bow)	647	34.8%
Tethered in gestation pen	432	30.6%

Table 11.1 continued

During gestation		
Type of confinement	No. of sows recorded	Incidence of traumatic injury
Running free in pen after having been tethered 1-4 weeks before inspection	262	14.0%

(from Backstrom, 1973)

Other evidence concerning the high incidence of traumatic injury suffered by tethered farrowing sows kept in crates has been given by Ekesbo (1973a); in one such system it reached 25% of all sows before the system was banned.

Close confinement by tethering is an obvious potential source of injury and has been studied by the Meat and Livestock Commission in a 3 month long study at one of the Commission's stations (House of Commons, 1981). The sows were examined 3 times and injury caused by the tether was classified as shown in table 11.2.

Table 11.2 Incidence of injury to sows as a result of tethering

Injury classification	Investigation No. 1. (37 sows) % sows in each category		Investigation No. 2. (132 sows) % sows in each category
0 - no effect		50	75
1 - reddening of neck, wetness	)		17
	)	47	
2 - crust formation, serum exudation	)		8
3 - severe inflammation with cuts		3	0
4 - severe lesions		0	0

(from House of Commons Agricultural Committee, 1981)

d) Sow health

Several authors have noted the relationship between severely confining animals and their subsequent health. Zintzen (1974) stated that tethered and crated sows are very prone to constipation at farrowing and Anon (1971) agreed. Zintzen also reported a susceptibility towards the mastitis-metritis-agalatia syndrome in such sows while Brooksbank (1958) claimed that the chronic form of erysipelas is more common in fat sows which have little exercise. In some units when tethers and sow stalls were first introduced there was an increased incidence of prolapsed anus and uterus, twisted bowel and stomach ulcers, as well as various types of leg weakness (Laird and Beaton, 1969). Saunders (1972) agreed that prolapse of the vagina and rectum are more common in sow stalls (particularly those incorporating a step and in which the sow may lie with her back end hanging over this) as the continual pressure of the viscera on the pelvis weakens the ligaments which holds them in place.

The Meat and Livestock Commission (House of Commons, 1981) reported various comments regarding the health of sows kept in confinement during pregnancy as compared to those in straw yards; in some units there were no differences while in others the incidence of farrowing fever, rectal prolapse and lameness was increased in totally confined sows.

Conclusion to the Literature Review

Due to the considerable length and complexity of the literature review, it may be helpful to summarise the main points which are relevant to this project. Sows and gilts show characteristic behaviour patterns at farrowing but both their behaviour and pattern of uterine contractions at farrowing can be greatly affected by environmental factors such as any form of stress, which usually leads to an interruption of myometrial activity and so prolongs the farrowing process. This in turn may lead either to an increase in stillbirth rate due to complete asphyxia or it may result in the production of piglets having a depressed viability due to partial asphyxiation. Such piglets will be unlikely to achieve rapid suckling and so may fail to obtain adequate warmth, nutrients and antibodies which the colostrum provides. Obviously, these piglets will suffer from high rates of neonatal mortality and so it is vital for the newly born piglet to be in as viable a state as possible, i.e. it needs to avoid suffering from asphyxia as a result of a prolonged farrowing.

In sow housing today, there is a definite move towards conditions which offer a very reduced amount of exercise; the sows thus confined may show marked changes in behaviour and it seems likely that these behavioural signs are indicative of stress. Apart from the welfare aspects of closely confining sows, there is a possibility that such a severe reduction in exercise will adversely affect their reproductive performance, possibly by acting as a stressor and prolonging farrowing time. There may be some controversy over the validity of extrapolating data from other species to the pig, but the overall trend shown in the literature appears consistent i.e. close confinement creates stress which prolongs the birth process

and results in more stillborn and low viability piglets. This hypothesis is examined experimentally in the following chapters.